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MEMORANDUM REPORT ARBRL-MR-02917

DEBRIS HAZARD FROM BLAST LOADED PLYWOOD SHEET CLOSURES

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May 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MEMORANDUM REPORT ARBRL-MR-02917	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DEBRIS HAZARD FROM BLAST LOADED PLYWOOD SHEET CLOSURES		5. TYPE OF REPORT & PERIOD COVERED Final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) George A. Coulter		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Ballistic Research Laboratory (ATTN: DRDAR-BLT) Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project Order No. DCPA 01-77-C-0193, Work Unit 1123-C
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research and Development Command US Army Ballistic Research Laboratory (ATTN: DRDAR-BL) Aberdeen Proving Ground, MD 21005		12. REPORT DATE MAY 1979 13. NUMBER OF PAGES 67
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Defense Civil Preparedness Agency Washington, D.C. 20301		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release: distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Basement Shelter; Blast closure; Blast Loading; Debris; Deflection Velocities; Failure mode; Plywood closures		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (mba)

Experimental results are presented from the blast loading of plywood sheet closures suitable for basement shelters. Pressure-time histories of the blast loading are shown and the panel deflection that occurs as result of the loading forces. High speed photographs illustrate the panel breakout and the debris hazard it creates.

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SUMMARY

I. INTRODUCTION

The work reported here is a part of a study funded by the Defense Civil Preparedness Agency under Project No. DCPA 01-77-C-0193, Work Unit 1123-C, entitled "Blast Loading in Existing Structures."

An experiment is described in which blast waves are used to load plywood sheet closures to failure.

II. EXPERIMENT

Panels of sheet plywood ranging in thickness from 1.27 cm to 2.54 cm were exposed face-on to the shock wave at the end of the Ballistic Research Laboratory 57.5 cm I.D. shock tube. Pressure-time histories of the loading and panel deflections-time histories were measured for the different panels. All panels were supported freely at four sides for these tests.

High speed photographs were taken of the panels yielding under the blast loading illustrating the potential debris hazard after the panel break-out occurs.

III. RESULTS AND CONCLUSIONS

Records of input shock wave loading and panel deflection histories are presented in the body of this report.

Panel deflection frequencies and amplitudes are presented for the variation in panel thickness and as a function of the loading force. Average deflection velocities for the panels from beginning of loading cycle to the maximum deflection were calculated as a function of the panel type. The ultimate strength under the blast load (load to break-through of panels) was found to be about eight times the calculated allowable static load values.

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I. INTRODUCTION

The Defense Civil Preparedness Agency (DCPA) has sponsored the present work at the Ballistic Research Laboratory (BRL) under Project Order No. DCPA 01-77-C-0193, Work Unit 1123-C entitled "Blast Loading in Existing Shelter Structures." The purpose of the present work is twofold. The first is to determine the break-out blast load of plywood sheets in order to make effective basement shelter window closures. The second purpose is to determine representative displacement velocities of the plywood panels as they are deflected by the blast wave loads.

The test procedure chosen was to expose an assortment of plywood sheets at the end of one of the Ballistic Research Laboratory shock tubes. The pressure of the incoming shock wave was to be measured to determine the reflected load at the test panel. The panel deflection under the blast load and the possible break-out were to be observed during the loading process. Section II describes the test setup and instrumentation used to do this.

II. EXPERIMENT

This section describes the test fixture to hold the plywood panels and the recording instrumentation used.

A. Test Setup

A test fixture was built for the plywood panels to hold them at the end of the BRL 57.5 cm diameter shock tube. Figure 1 shows the test fixture with a panel in place. Details are shown in the sketch of Figure 2.

Each 47 cm square panel was simply supported on all four edges with an overlap of 3.81 cm all around as suggested in Reference 1. Two small finishing nails (1.44mm dia x 38.1mm long - 4d) were driven into the bottom of the panels to act as standoffs (1.27 cm) to maintain the correct vertical overlap needed. Rubber bands were affixed to the outside (downstream) face of the panels to assure that each test panel was tight against the backup flange.

The test setup was completed with a high speed camera, pressure transducer, and deflection follower. These are described in Section B below.

[1] *H. L. Murphy, "Upgrading Basements for Combined Nuclear Weapon Effects: Predesigned Expedient Options," Technical Report SRI Project 5622, Stanford Research Institute, Menlo Park, CA 94025, October 1977.*

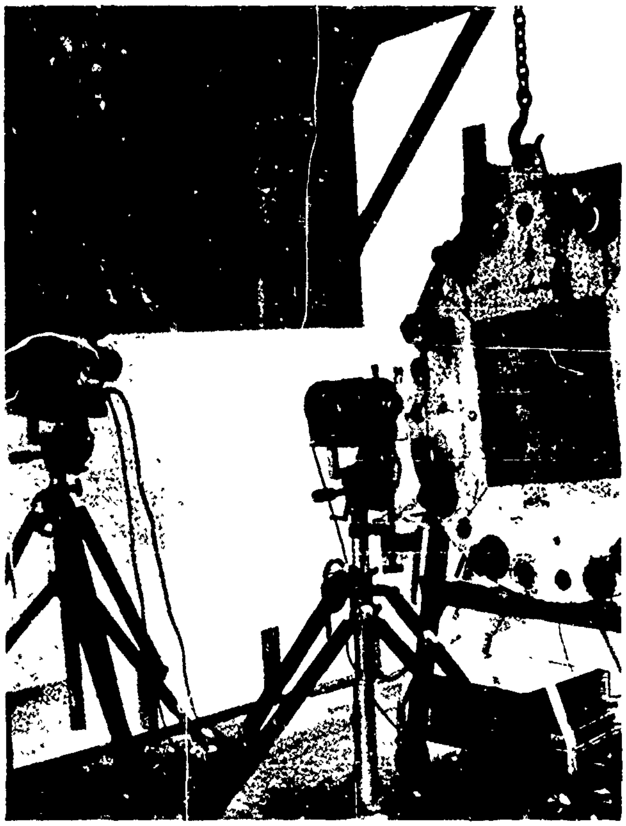

Figure 1. Test Setup

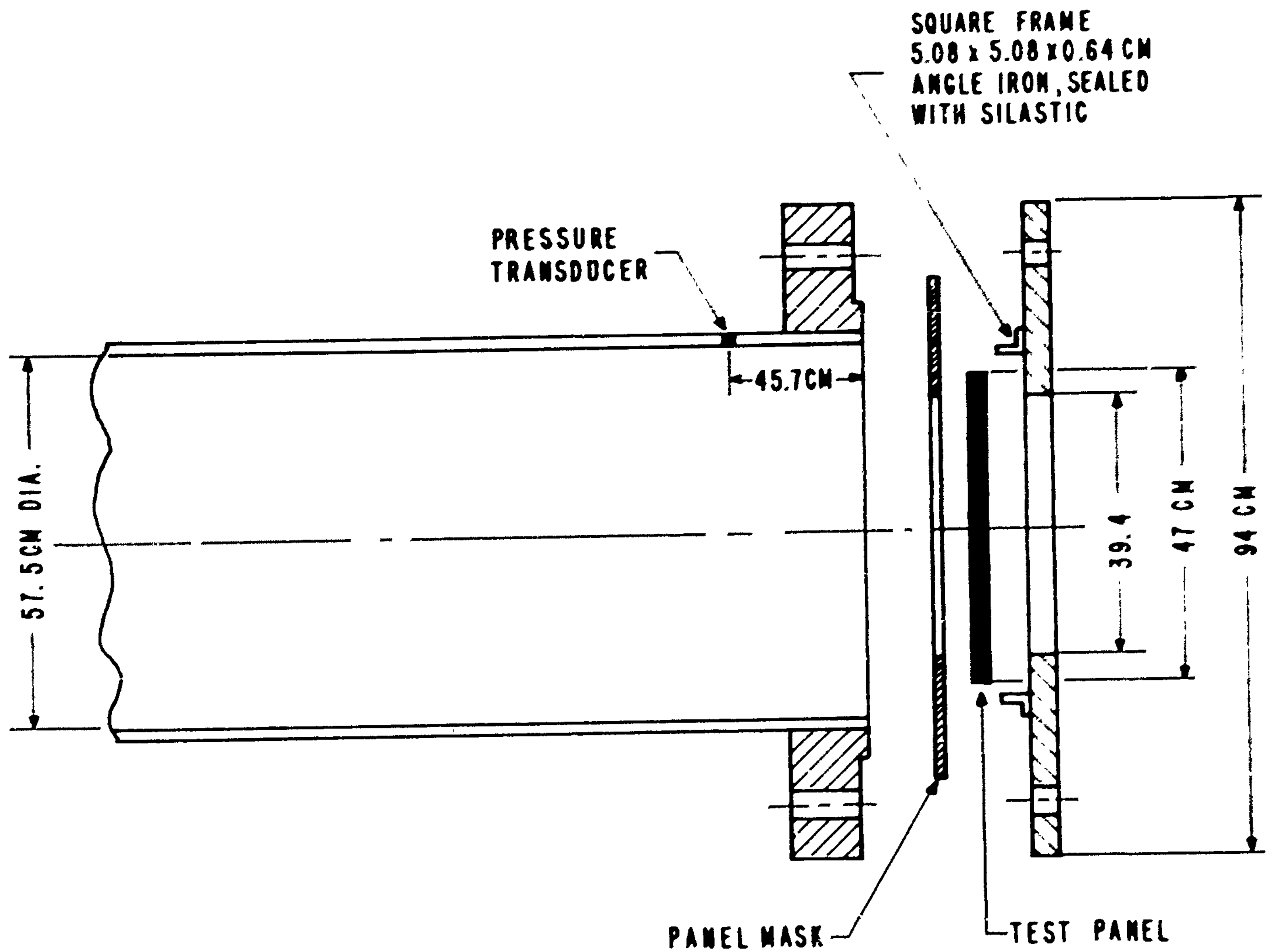

Figure 2. Panel Holder

B. Instrumentation

The pressure recording consisted of a PCB Model 113M28 quartz transducer with a builtin voltage amplifier. The signal from the transducer was recorded by an FM Honeywell 7600 tape recorder. A quick look oscillograph playback was available at the test site. The analog data was then converted to digital, and plotted with engineering units.

The displacement data was acquired with an OPTRON Model 501 Electro-Optical Displacement Follower[2]. A target discontinuity (a black balsa wood tab glued to the center of the panel) was tracked optically in the intensity of light reflected or emitted from the target surface. The optical target image was converted to an electron image in which the electronic density was proportional to the corresponding light intensity. Again,the electrical signal was recorded by the 7600 FM tape machine. The data reduction was the same as that for the pressure records.

A high speed camera (Red Lake Hycam) running at 5000 pps completed the instrumentation.

III. RESULTS

The results are presented in two groups: (a) the pressure and deflection traces, and (b) the high speed photographs.

A. Pressure and Deflection Traces

A typical series of loading and deflection records are shown in Figures 3 and 4 for the 1.59 cm plywood sheet panels as the shock overpressure was increased. As the pressure load increased, the panel frequency decreased with the increased deflection until some panel cracking occurred. The panels tended in general to show decreased oscillation as they approached rupture or break-out under increased loads. See the Appendix to this report for other records.

Figures 5 through 10 show a variety of break-out patterns illustrated by the post-shot photographs. As the load approached the ultimate yield value, some cracking of the outer plies occurred (Figure 8). As the load reached the ultimate yield value, large break-out occurred (Figures 5 and 9). In some instances, almost all the panel was blown out (Figures 6 and 7) as the loading pressure was increased past its ultimate yield point (burst point).

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[2]*See company manual "Model 501 Optical Displacement Follower," OPTRON, Divison of Univ. Tech., Inc., 30 Hazel Terrace, Woodbridge, Conn. 06525.*

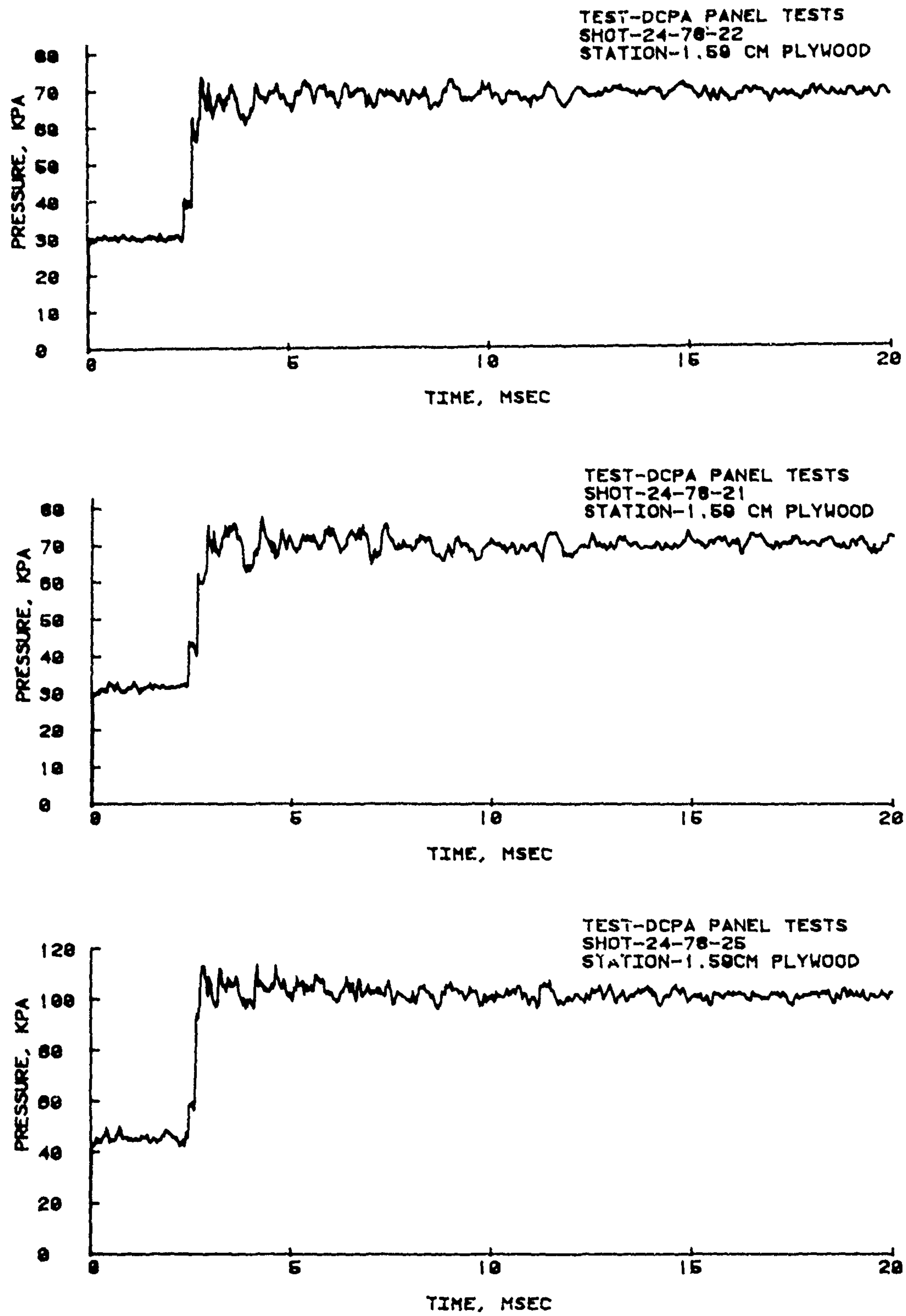


Figure 3. Pressure-Time Loading Records

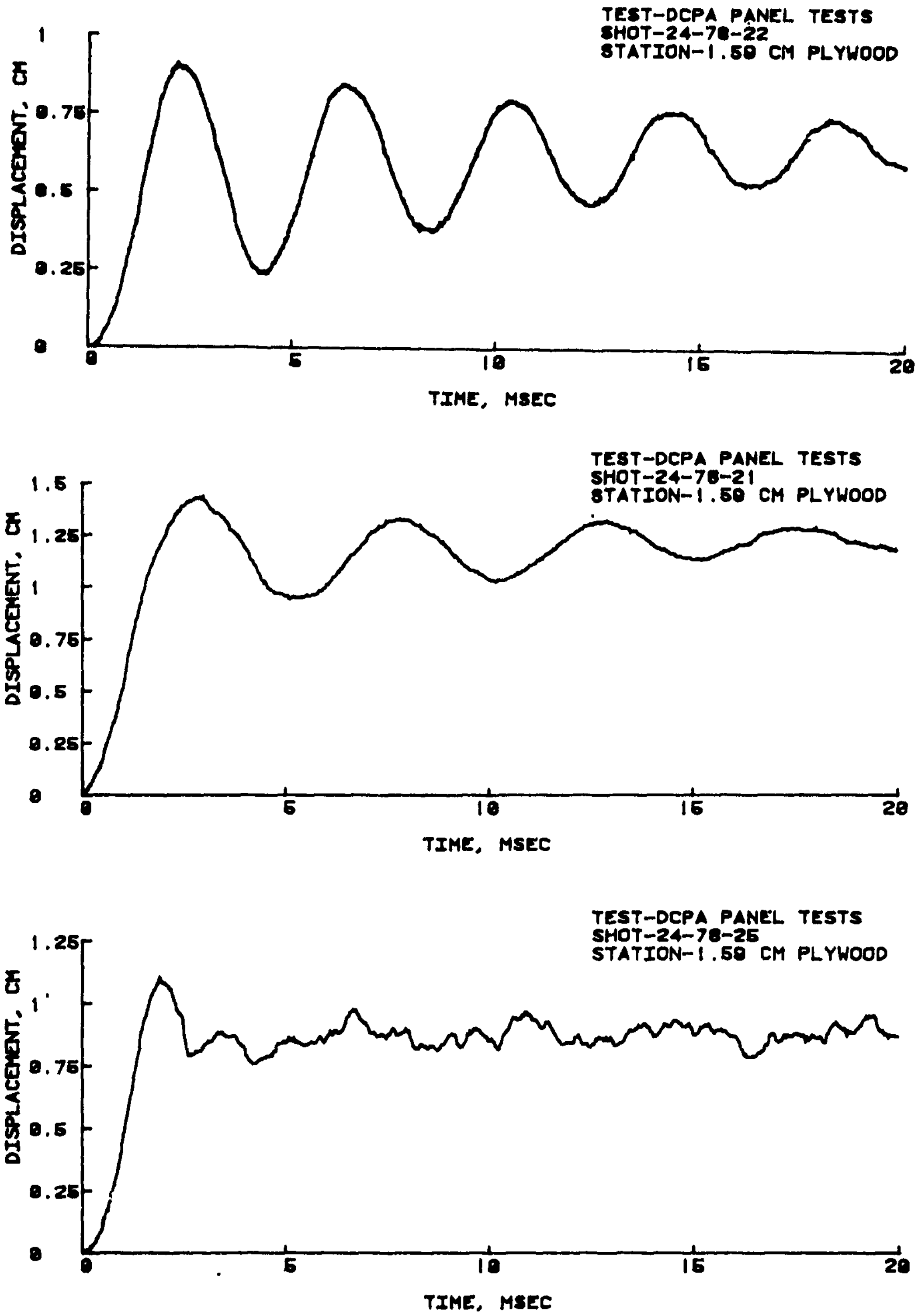
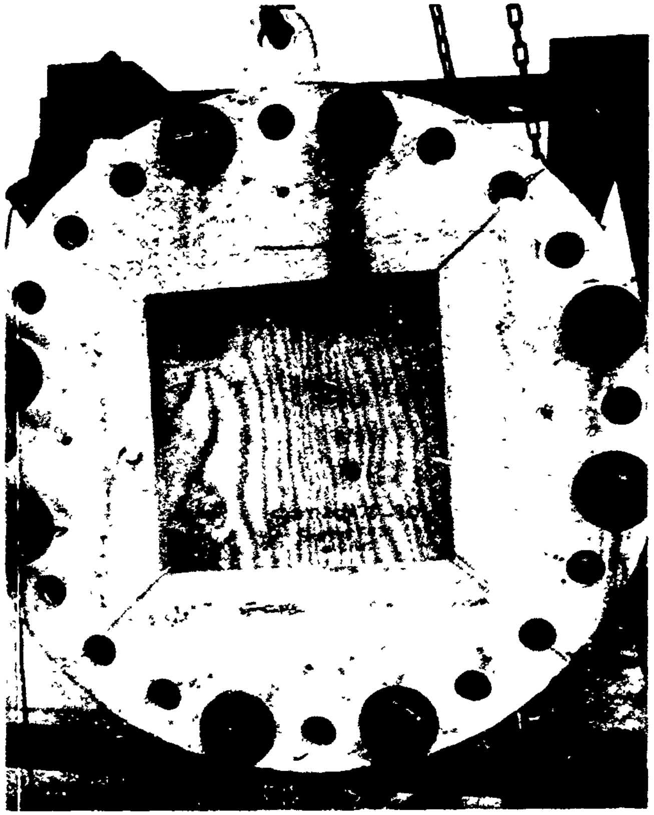
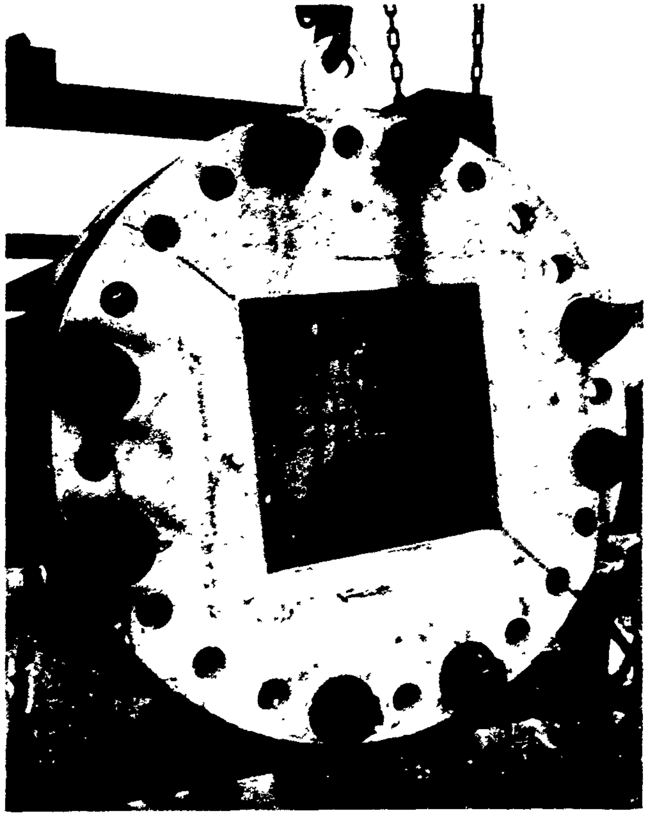


Figure 4. Deflection-Time Records

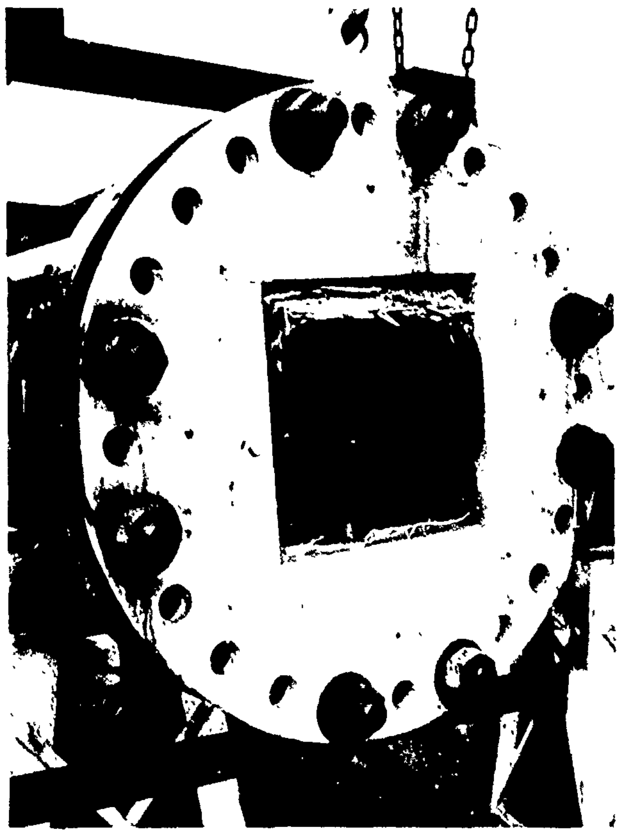


(A) PRE-SHOT 24-78-30



(B) POST-SHOT 24-78-30

Figure 5. 1.27 cm A-D Interior Plywood - Loading Pressure 93.8 kPa (13.6 psi)



POST-SHOT 24-78-31

Figure 6. 1.27 cm A-D Interior Plywood - Loading Pressure 84.1 kPa (12.2 psi)

(A) PRE-SHOT 24-78-62

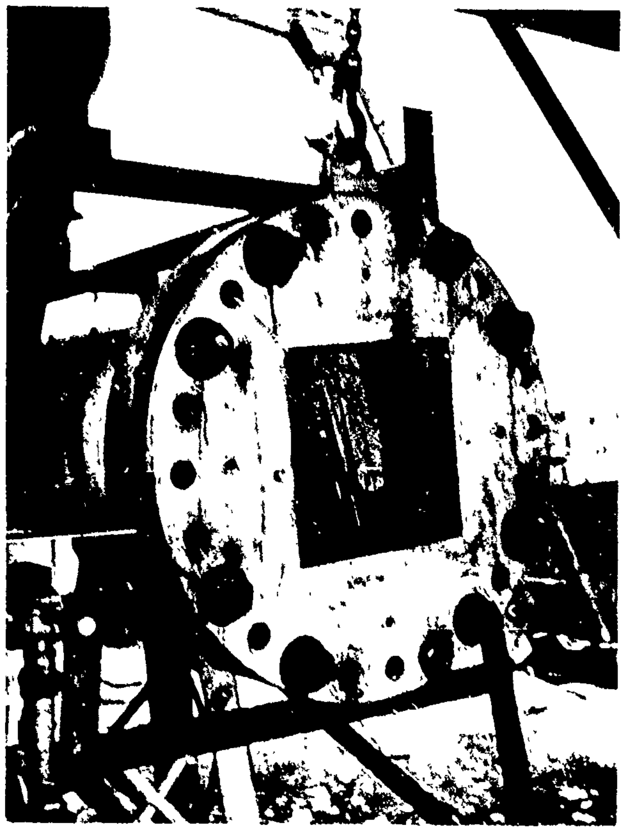
(B) POST-SHOT 24-78-62

Figure 7. 1.59 cm B-B Class 1 Exterior Plywood - Loading Pressure
170.3 kPa (24.7 psi)

(A) PRE-SHOT 24-78-50

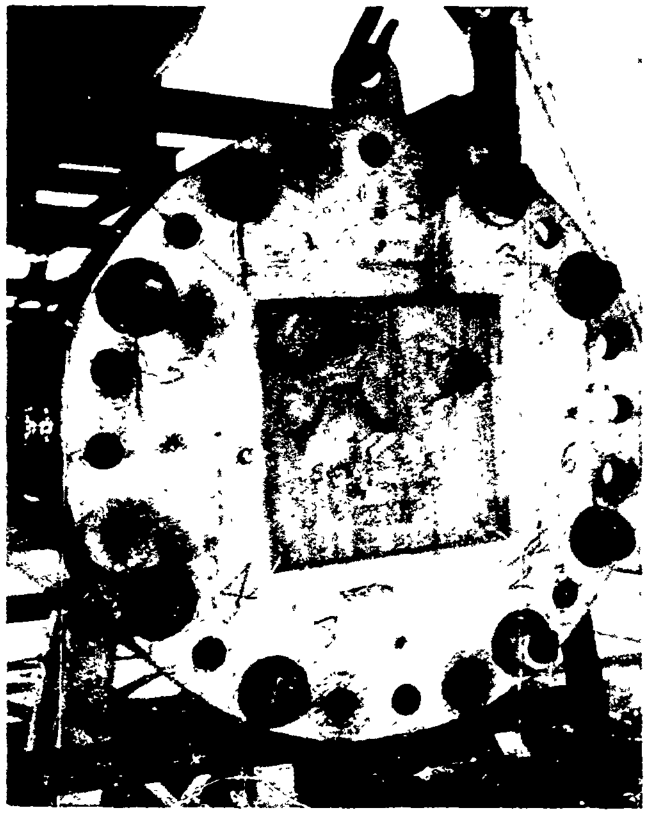
(B) POST-SHOT 24-78-50

Figure 8. 1.90 cm A-C Exterior Plywood - Loading Pressure 109.6 kPa (15.9 psi)

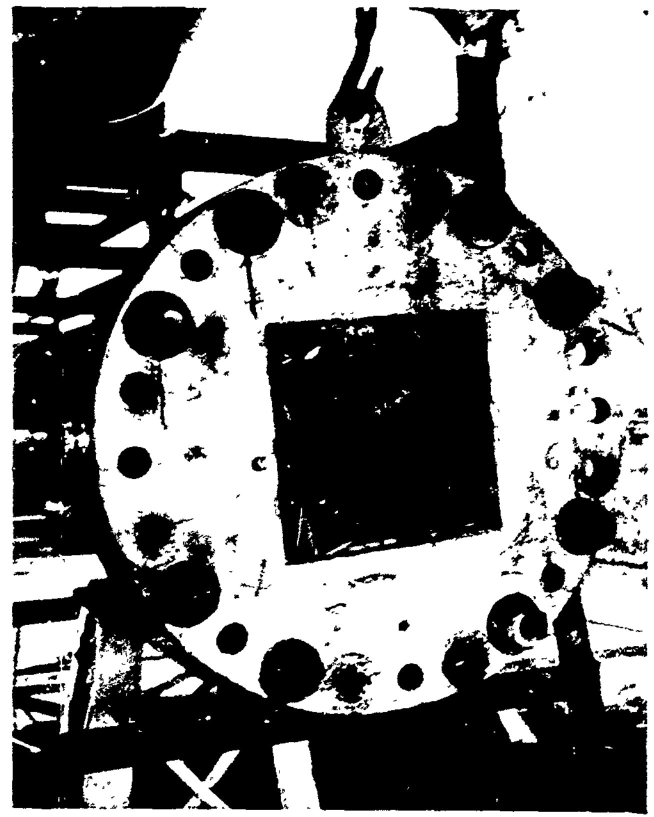


POST-SHOT 24-78-60

Figure 9. 1.90 cm A-C Exterior Plywood. Loading Pressure 122.1 kPa (17.7 psi)



(A) PRE-SHOT 24-78-51



(B) POST-SHOT 24-78-51

Figure 10. 1.90 cm A-C Exterior Plywood - Loading Pressure 162.5 kPa (22.1 psi)

Table I summarizes the shot conditions and panel damage as a function of blast load applied. One result that seemed to occur for all panels was that panels seemed to resist the increase in blast loading with only slight damage, some cracking of the plies, until the ultimate yield level of blast pressure was reached. The failure then was catastrophic. Large pieces of the panels were blown out. If the panels were being used as shelter closures, a debris hazard would exist at this point of exposure.

For the 1.27 cm panel (1/2 in.) tested, the panel breakup occurred at about 85.5 kPa (12.4 psi) reflected blast load. For the 1.59 cm panel (5/8 in.) the loading was 176.5 kPa (25.6 psi), for the 1.90 cm panel (3/4 in.) the loading was 137.9 kPa (20 psi), and for the 2.54 cm panel (1 in.) the loading was 337.8 kPa (49 psi). Notice that the 1.59 cm panel (5/8 in.) B-B class 1 exterior exceeded the strength of the 1.90 cm (3/4 in.) panel. One explanation might be that the B-B class 1 is a plywood intended for use as concrete forms with a high reuse factor intended. Also, the panels were free from knots, whereas the 1.90 cm panels contained many knots. Section IV, Analysis, contains the published specification for the plywood grades used to make up the panels.

B. High Speed Photographs

On some of the shots a high speed camera (5000 pps) was used to monitor the break-out of the panel under the blast load. Figures 11 and 12 illustrate two such shots. Initial splintering occurred as the outside plies were broken. As further cracking of the remaining plies took place, splinters, panel pieces, and in some cases, half-panels were torn loose. Debris was found in an impact area 25 m wide by about 100 m long.

A look at the average velocity centers of the panel's deflection under the blast load will give some indication of the potential debris problem. Table II lists some of these average velocities. Those measured from the option follower (OF) records were calculated by dividing the displacement of the first peak by the time to reach that peak. When the high speed photographs were used for the velocity calculation, the frame time from discernable motion to time of maximum forward center displacement was used. Average velocities for the small panel displacements were as small as 3 - 5 m/s. For near break-out conditions the average velocity was in the range of 20 - 25 m/s. A potential debris problem would exist here at the break-out point if the panels had been used for basement shelter closures.

Section IV, Analysis, will describe the calculations needed to arrive at the ultimate load (burst-pressure) for the plywood sheet closures. Only slight splintering would occur below the calculated burst point and no debris problem would be expected below that point.

Table I. Loading Data

Shot No.	Type Panel	Ambient Pressure kPa	Ambient Pressure psi	Shock Overpressure kPa	Shock Overpressure psi	Reflected Overpressure kPa	Reflected Overpressure psi	Panel Deflection cm.	Panel Deflection in.	Deflection Time ms	Panel Vibration Hz	Panel Damage	Remarks
24-78-19	1.27cm A-D	102.5	14.87	22.6	3.28	49.4	7.17	1.12	0.44	2.1	215	None	All panels
18	Int,5plies	102.5	14.87	22.8	3.31	49.8	7.23	-	-	-	-	Small cracks	were simply
17	Group I	102.5	14.87	25.9	3.76	57.3	8.31	2.46	0.97	2.1	-	Cracks-1 ply	supported on
20		102.2	14.83	26.0	3.77	57.4	8.33	0.50	0.20	1.95	-	Cracks-2 plies	four edges.
16		102.4	14.86	26.8	3.89	59.4	8.62	2.59	1.02	3.0	-	Cracks-1 ply	
31		101.8	14.76	36.6	5.31	84.1	12.2	-	-	-	-	Blown apart	
29		101.8	14.76	37.8	5.48	86.9	12.6	-	-	-	-	Broken-4 plies	
30		101.8	14.76	40.4	5.86	93.8	13.6	-	-	-	-	Blown Apart	
28		101.8	14.76	50.4	7.31	120.7	17.5		-	-	-	Blown to bits	
63		102.7	14.89	50.9	7.38	122.0	17.7	-	-	-	-	90% out	
24-78-22	1.59 cm	102.2	14.83	30.1	4.36	67.4	9.78	0.90	0.35	2.25	243	None	
23	B-B class	101.8	14.76	30.4	4.41	68.3	9.90	0.83	0.33	1.95	267	None	
21	1 Ext,	102.2	14.83	31.4	4.55	70.3	10.2	1.43	0.55	2.85	206	Small cracks	
24	5 plies	101.8	14.76	33.0	4.78	74.5	10.8	0.83	0.33	1.80	261	None	
25		101.6	14.76	45.5	6.60	107.6	15.6	1.09	0.43	1.95	-	Cracked-2 plies	
26		101.8	14.76	58.3	8.46	143.4	20.8	1.06	0.42	1.20	-	Ply broke loose	
62		102.7	14.89	67.6	9.8	170.3	24.7	-	-	-	-	80% out	
27		101.8	14.76	68.9	10.0	174.4	25.3	1.69	0.67	1.50	292	Panel deformed	
24-78-48	1.90 cm	102.6	14.88	41.0	5.95	95.1	13.8	1.56	0.61	1.80	350	None	
50	A-C Ext,	102.7	14.89	46.3	6.72	109.6	15.9	1.49	0.59	-	239	Cracked-2 plies	
60	5 plies	102.7	14.89	51.0	7.40	122.0	17.7	-	-	-	-	50% out	
59	Group I	102.7	14.89	55.2	8.01	133.8	19.4	-	-	-	-	Blown to bits	
52		102.5	14.87	57.6	8.35	140.7	20.4	0.90	0.35	1.50	-	Cracked-1 ply	
51		102.7	14.89	61.5	8.92	152.4	22.1	1.99	0.78	2.25	-	Ring left	
49		102.8	14.91	72.2	10.5	184.8	26.8	-	-	-	-	Blown to bits	
24-78-53	2.54 cm	102.5	14.87	66.3	9.62	166.2	24.1	0.63	0.25	1.35	435	None	
54	A-C Ext,	102.4	14.86	98.5	14.3	268.9	39.0	1.39	0.55	1.95	351	Cracked-1 ply	
55	7 plies	102.4	14.85	105.7	15.3	292.3	42.4	1.96	0.77	3.3	-	Cracked-1 ply	
56	Group I	102.3	14.84	110.7	16.1	311.6	45.2	1.89	0.74	3.0	-	Cracked-1 ply	
65		102.5	14.86	117.5	17.0	333.0	48.3	-	-	-	-	Blown out	
64		102.5	14.86	117.4	17.0	333.0	48.3	-	-	-	-	90% out	
57		102.5	14.87	119.6	17.3	340.6	49.4	>2.29	0.90	1.95	-	Blown out	
58		102.7	14.89	119.3	17.3	340.6	49.4	2.16	0.85	-	-	Cracked-2 plies	

SHOT 24-78-26

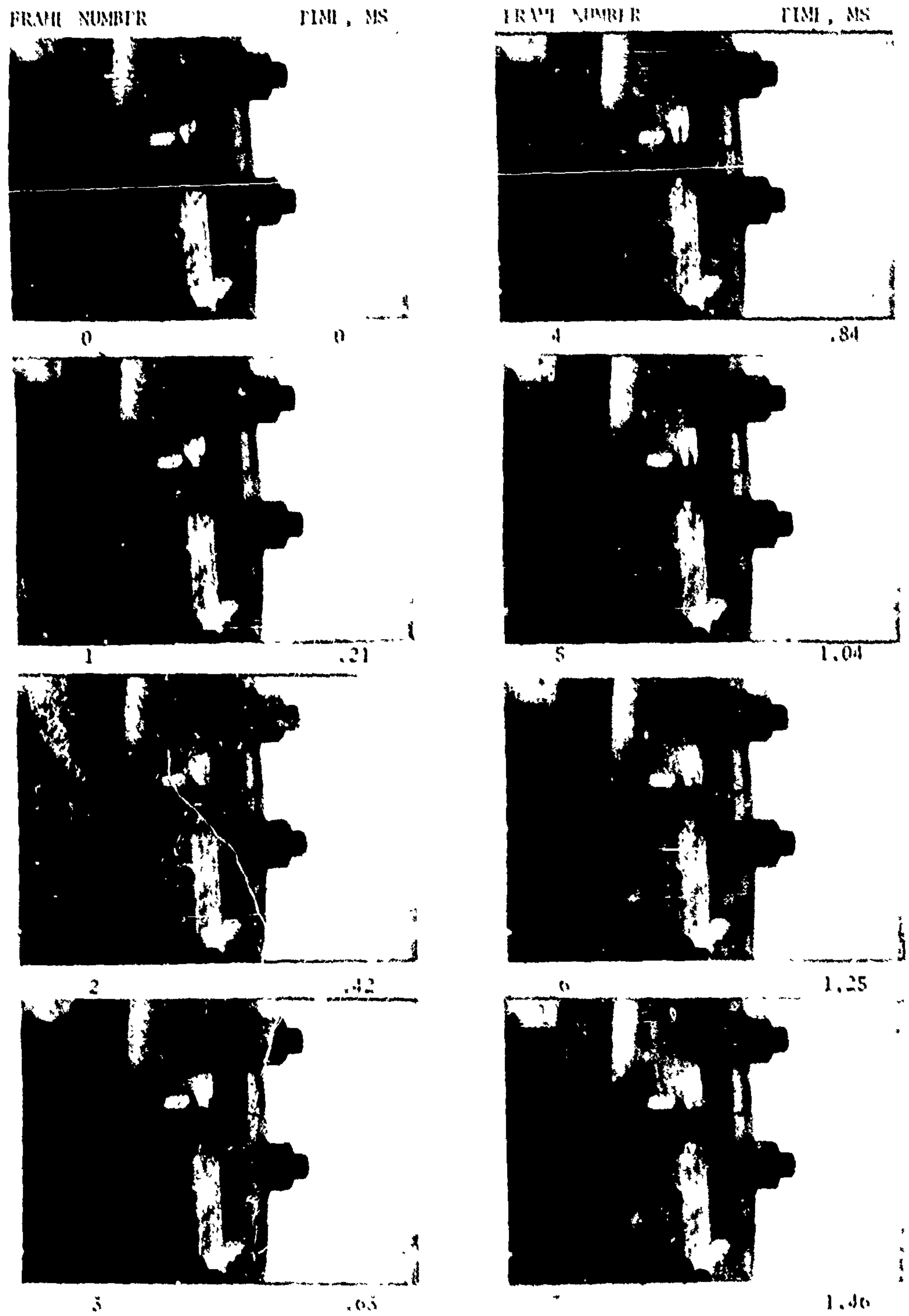
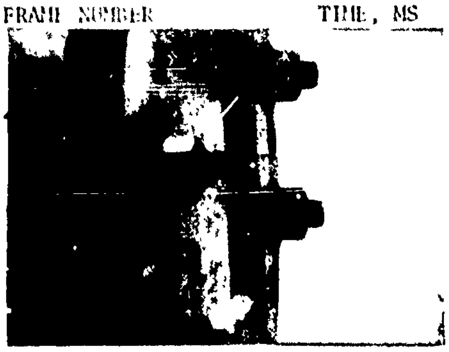


Figure 11. High Speed Photographs Shot 24-78-26

SHOT 24-78-26

FRAME NUMBER TIME, MS



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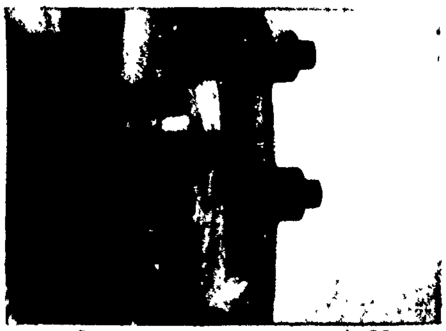

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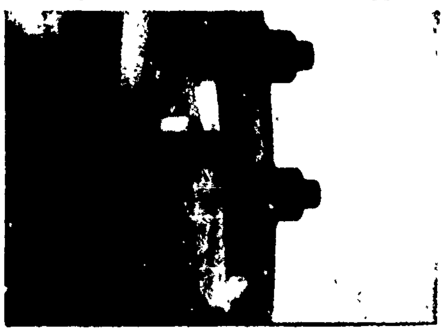

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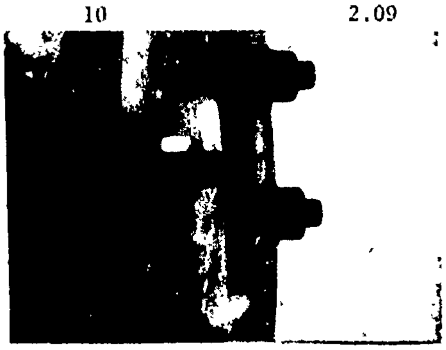

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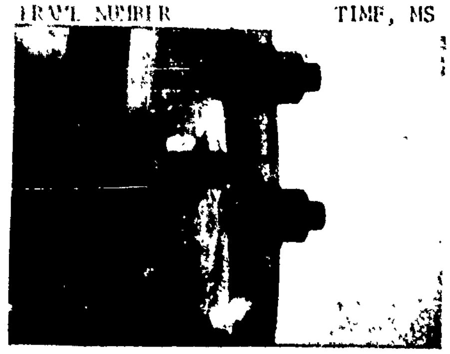
FRAME NUMBER TIME, MS



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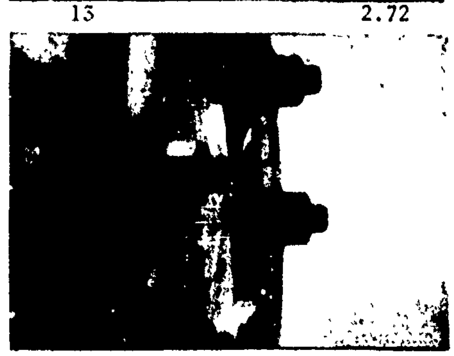
13 2.72



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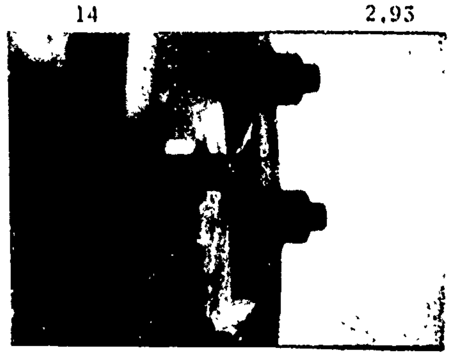

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Figure 11 (Cont'd). High Speed Photographs - Shot 24-78-26

SHOT 24-78-27

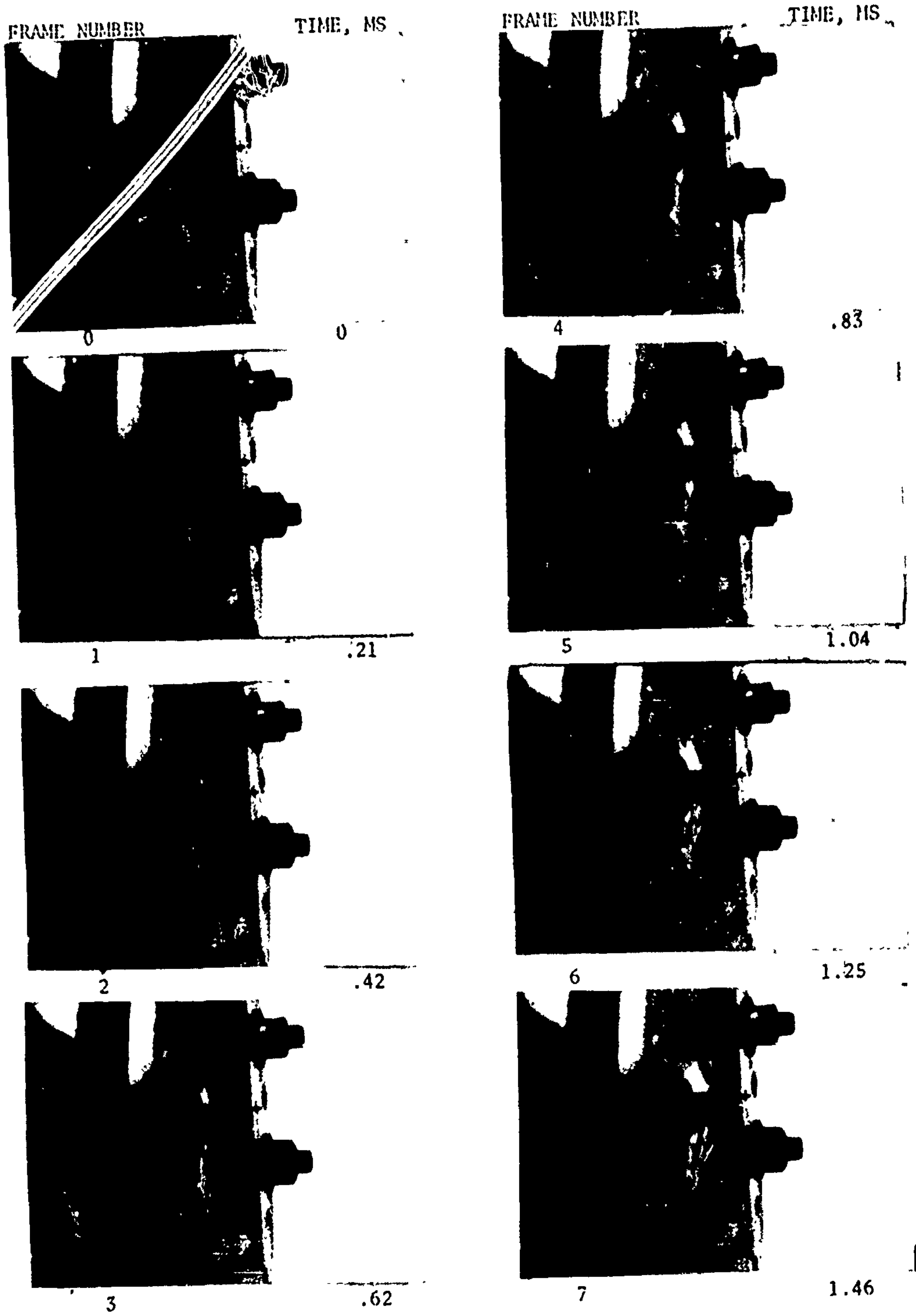


Figure 12. High Speed Photographs - Shot 24-78-27

SHOT 24-78-27

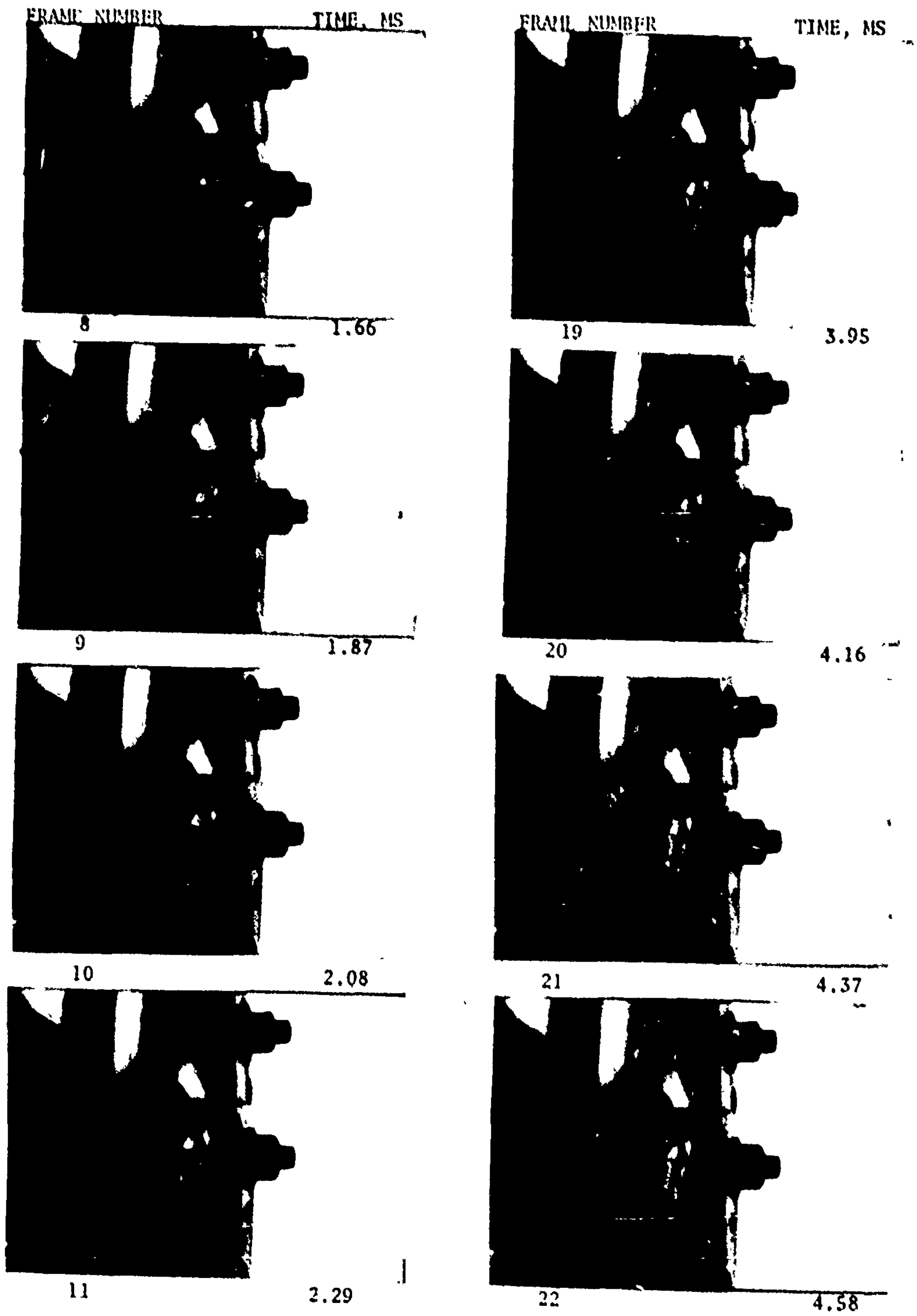


Figure 12 (Cont'd) High Speed Photographs - Shot 24-78-27

Table II. Average Panel Deflection Velocity to Reach First Maximum

Shot No.	Type Panel	Reflected Load kPa	Deflection cm	Time ms	av. Velocity m/s	Remarks
24-78-19	1.27cm A-D	49.4	1.12	2.10	5.3	OF
20	Interior	57.4	0.50	1.95	3.3	OF
16	Group I	59.4	2.59	3.00	8.6	OF
17		57.3	2.12	2.46	8.6	HSC
24-78-22	1.59cm B-B	67.4	0.90	2.25	4.0	OF
23	Class 1	68.3	0.83	1.95	4.3	OF
21	Exterior	70.3	1.43	2.85	5.0	OF
24		74.5	0.83	1.80	4.6	OF
25		107.6	1.09	1.95	5.6	OF
26		143.4	3.70	2.93	12.5	HSC
27		174.4	3.18	1.87	17.0	HSC
24-78-48	1.90cm A-C	95.1	1.56	1.80	8.7	OF
52	Exterior	140.7	0.90	1.50	6.0	OF
51	Group I	152.4	1.99	2.25	8.8	OF
49		184.8	2.09	0.82	25.5	HSC
24-78-53		166.2	0.63	1.35	4.7	OF
54		268.9	1.39	1.95	7.1	OF
55		292.3	1.96	3.30	5.9	OF
56		311.6	1.89	3.00	6.3	OF
57		340.6	>2.29	1.95	>11.7	OF

NOTE: (1) OF means data from optron follower records.
(2) HSC means data from high speed photographs.

IV. ANALYSIS

A prediction method proposed by H. L. Murphy (Reference 1) was used to arrive at the expected loads needed to cause ultimate failure (break-through) of plywood sheet closures. This method is outlined briefly below.

Plywood weight is ignored as dead load, single spans are used with uniform loads, and simple supports are assumed. The equations listed have no hidden units in the constants.

For uniform loads based on allowable bending stress:

$$P_b = 8 F_b S/\ell^2, \tag{1}$$

where

P_b = allowable load - bending moment (kPa),

F_b = allowable bending stress (kPa),

S or Ks = effective section modulus (cm^3/cm width), and

ℓ = clear span (cm).

For uniform loads based on allowable rolling shear stress:

$$P_{st} = 2 F_s (Ib/Q)/\ell, \tag{2}$$

where

P_{st} = allowable load-rolling shear stress (kPa),

F_s = allowable rolling shear stress (kPa),

(Ib/Q) = rolling shear constant (cm^2/cm width), and

ℓ = clear span (cm).

The useful allowable load P_m becomes:

$$P_m = P_b \text{ or } P_{st}, \text{ whichever is smaller (kPa)} \tag{3}$$

For the present test panels $P_m = P_b$.

For bending deflection (elastic) under uniform load:

$$Y_b = P_m \ell^4/(76.8\ I\ (1.1\ E)), \tag{4}$$

where

Y_b = bending deflection (elastic) under uniform load (cm),

I = effective moment of inertia (cm^4/cm width),

E = modulus of elasticity (kPa), and

ℓ = clear span (cm).

For shear deflection (elastic) under uniform load:

$$Y_s = P_m C t^2 \ell^2/(106 E I), \qquad (5)$$

where

Y_s = shear deflection (elastic) under uniform load (cm),

C = 120 or 60, for panels applied with face grain perpendicular to or parallel to supports, respectively, and

t = nominal panel thickness (cm).

For combined bending and shear deflection (elastic) either add Y_b and Y_s from Equations 4 and 5 or use Equation 4 only with the constant 1.1 dropped from the equation.

For the plywood bearing face under uniform load (ends over simple supports):

$$\ell_e = \ell/(2((F_{c\perp}/P_m) - 1)), \qquad (6)$$

where

ℓ_e = required plywood end bearing length at each end of panel (cm), and

$F_{c\perp}$ = allowable bearing stress on the plywood face, for load perpendicular to plane of outer ply actually in bearing (kPa).

Reference 1 recommended that ℓ_e be at least 3.8 cm; this recommendation was followed for the plywood panels just tested.

Ultimate yields for the panels were calculated by using values furnished in Reference 3 of materials strength parameters to give the

[3] *"Plywood Design Specifications," American Plywood Association, P.O. Box 2277, Tacoma, Wash. 98401, December 1976.*

allowable loads. The allowable loads for panels with two ends supported were corrected to panels supported on four sides. This was done by reducing the value of $P_m = P_b$ associated with the larger Y_b by multiplying by the ratio of the smaller Y_b to larger Y_b. The total capacity, P_m total, equals the sum of the reduced value plus the unchanged P_b associated with the smaller Y_b. These values were then multiplied by a factor of four as suggested by Murphy[1] to give the expected blast load to cause ultimate panel failure. Table III lists these expected values.

A study of the table shows the experimental values of loads needed to fail the panels still exceeded the four times the allowable loads suggested by Murphy[1] The actual loads measured exceeded predictions by factors ranging from 1.4 to 3.0. This in addition to the four times factor which had been included in the predictions already. Therefore, the blast loads expected to cause ultimate failure of the plywood sheet panels tested were about eight times the allowable static loads calculated by the handbook methods.

V. SUMMARY AND CONCLUSIONS

The Defense Civil Preparedness Agency, as a part of its program to upgrade existing shelters, has had a design manual (Reference 1) prepared which describes and lists pre-designed plywood sheet closures. The closures are designed to be used for basement shelter openings, windows, for example. The intent was to allow home and commercial basements to be upgraded to resist increased levels of blast pressure over the basements present ability to protect the shelterees.

The design procedure followed was to take the handbook characteritics (Reference 3) and equations to calculate the allowable static loads for a number of commercially available plywood sheets. A dynamic factor of four was applied to the static values calculated to arrive at the ultimate strength of various plywood panels under blast loading. The present work was initiated to try to verify the range of ultimate strength values arrived at in the design manual.

Accordingly, a set of plywood sheet panels were exposed (exposed area 39.37 x 39.37 cm^2) to a reflected shock overpressure loading at the end of the BRL 57 cm shock tube. Panels of various thickness (1.27, 1.59, 1.90, and 2.54 cm) were loaded to bursting, while simply supported on all four sides. Input shock pressure and center-point panel deflection were monitored during the shot series. High speed photography was used during part of the shot series to observe the breaking sequence.

Loading data - pressure load, panel deflection, and panel vibration frequency - were found for the test panels. Bursting loads were found to vary from about 85.5 kPa (12.4 psi) for 1.27 cm (1/2 in.) thickness to 338 kPa (49 psi) for the 2.54 cm (1 in.) panels. Vibration frequencies varied between 200 to 350 Hz for the test panels.

Table III. Properties for Plywood with Predicted Values of Ultimate Yield for Applied Blast Loads

Panel Type	Grade Stress Level	F_s kPa	F_b kPa	E kPa	Parallel			Perpendicular			ℓ cm
					I cm^4/cm	S cm^3/cm	(Ib/Q) cm^2/cm	I cm^4/cm	S cm^3/cm	(Ib/Q) cm^2/cm	
1.27 cm A-D Interior Group 1	S-3 Dry	330.9	11,376	12.4×10^6	0.105	0.143	1.023	0.024	0.080	0.655	39.37
1.59 cm B-B Class 1 Exterior	S-2 Dry	365.4	11,376	12.4×10^6	0.176	0.190	1.331	0.061	0.125	0.830	39.37
1.90 cm A-C Exterior Group 1	S-1 Dry	365.4	13,789	12.4×10^6	0.269	0.243	1.688	0.126	0.208	1.033	39.37
2.54 cm A-C Exterior Group 1	S-1 Dry	395.4	13,789	12.4×10^6	0.577	0.392	1.880	0.345	0.399	1.617	39.37

Table III (Cont'd) Properties for Plywood with Predicted Values of Ultimate Yield for Applied Blast Loads

Panel Type	Allowable Loads: Parallel P_b, kPa	Allowable Loads: Perpendicular P_b, kPa	Bending Deflection: Parallel Y_b, cm	Bending Deflection: Perpendicular Y_b, cm	Total Allowable Load P_m total, kPa	Ultimate Yield, kPa: Predicted*	Ultimate Yield, kPa: Experiment	Remarks
1.27 cm A-D Interior Group 1	8.40	4.70	0.20	0.50	10.28	41.1	85.5	Rolling shear stress loads, P_{st}, are not shown since they are larger than bending stress load, P_b, for these panels
1.59 cm B-B Class 1 Exterior	11.16	7.34	0.16	0.31	14.95	59.9	176.5	
1.90 cm A-C Exterior Group 1	17.29	14.80	0.16	0.30	25.18	100.7	137.9	Panels were 39.37 cm x 39.37 cm simply supported on four sides with 3.8 cm bearing face all around.
2.54 cm A-C Exterior Group 1	27.90	28.40	0.12	0.21	44.12	176.5	337.8	

*Predicted values were calculated by the methods of Reference 1.

The results from the tests showed the burst pressures to exceed the calculated ultimate strength values in the closure design manual by 1.4 to 3.0 times. Ultimate yield values for blast protections (bursting loads, should probably be listed about eight times the allowable static loads calculated.

Interestingly, almost no damage occurred to a test panel for loads just below the bursting pressure. For pressures somewhat above the burst level, the panel would nearly always blow out. A half-panel to perhaps a 10% ring might be left of the panel in the panel holder. At loads much higher than burst pressure, it was difficult to find recognizable pieces of the panel in the impact area.

A study of deflection-time records and high speed photographs gave some insight into the possible debris hazard caused by the rupturing panels. Average center line deflection velocities (for maximum non-burst deflection) were measured from about 3 or 5 m/sec to perhaps 20 - 25 m/s for bursting panels. Additionally, debris from the broken test panels was found spread over an area 25 m wide by perhaps a 100 m long. Sizes of debris varied from splinters to half-panels. In general, in spite of a possible debris problem at the burst point, simple plywood sheet panels should work well as small closures for the windows of basement shelters to upgrade the level of blast protection.

ACKNOWLEDGMENTS

The author wishes to thank Messrs. Kenneth Holbrook and Vincent King for the careful experimental work performed at the BRL Shock Tube Facility.

APPENDIX

PRESSURE-TIME AND DEFLECTION-TIME TRACES

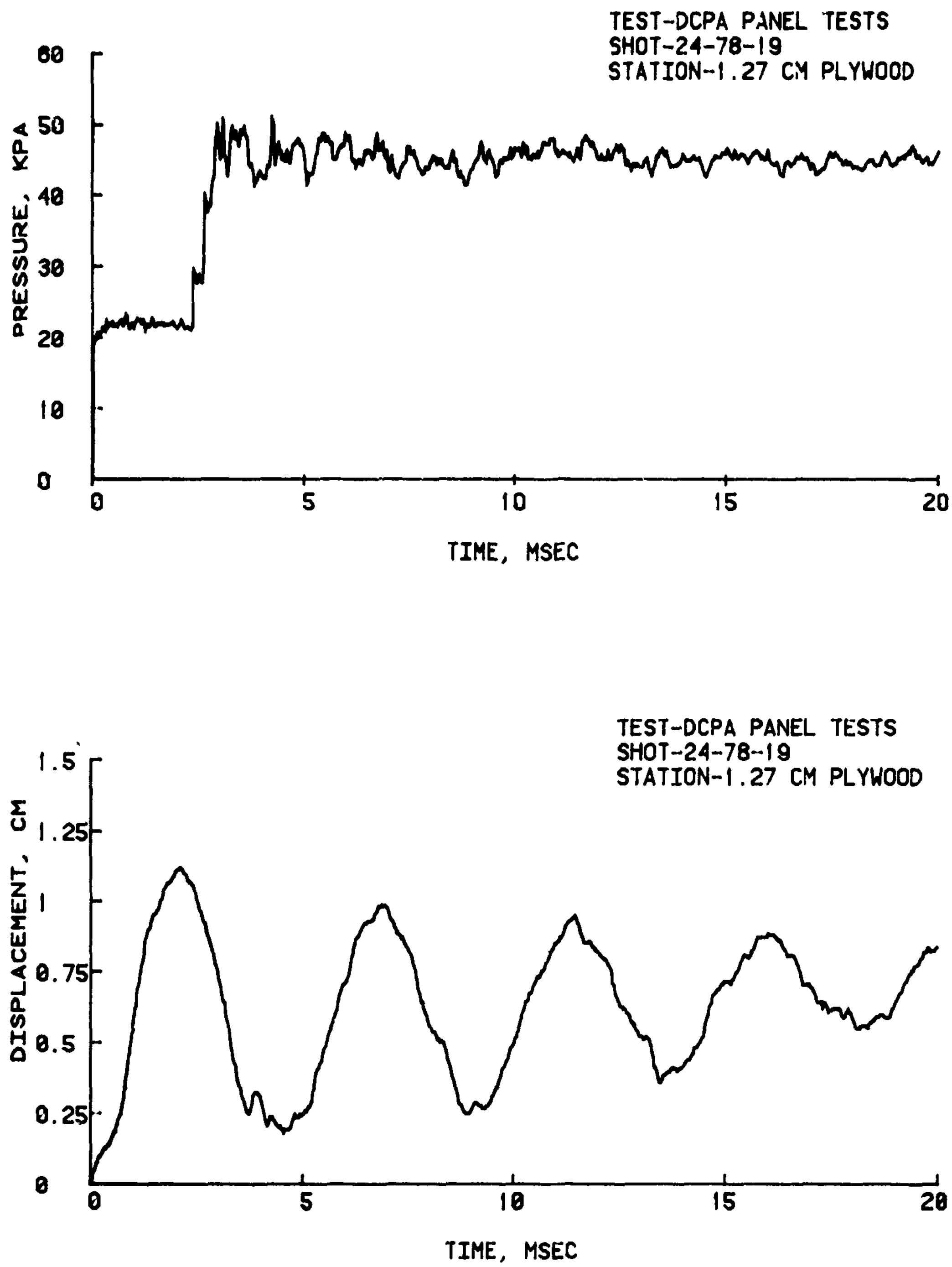
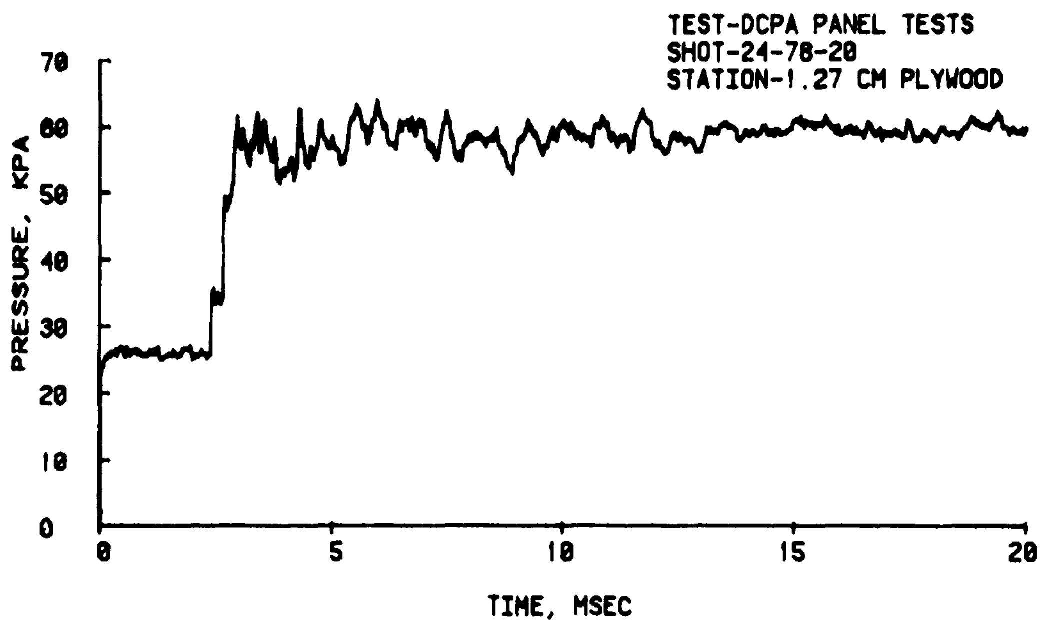
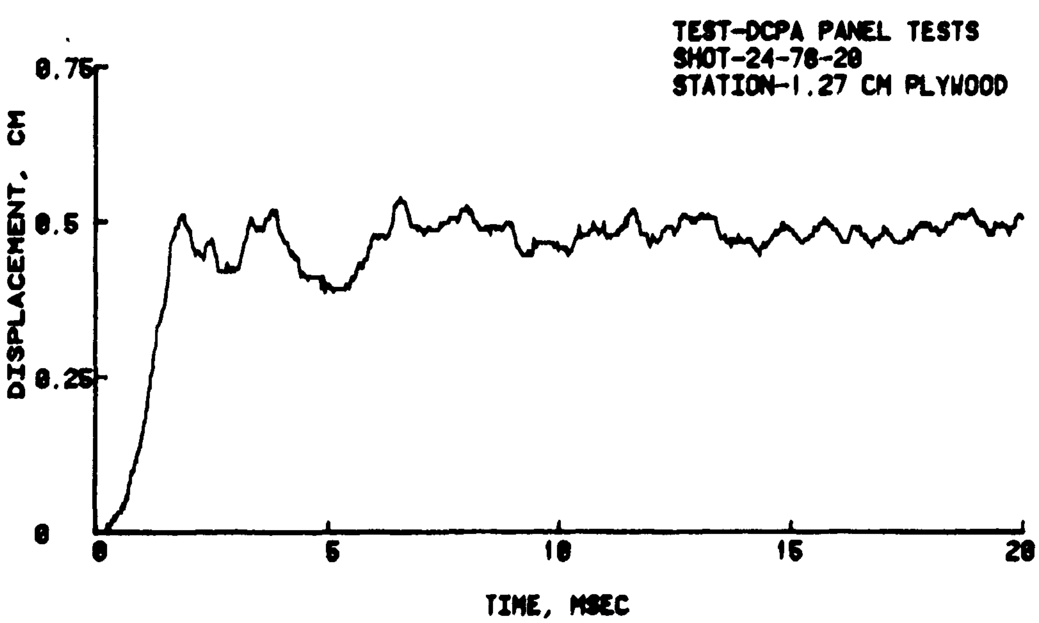


Figure A-1. Records for 1.27 cm Panels





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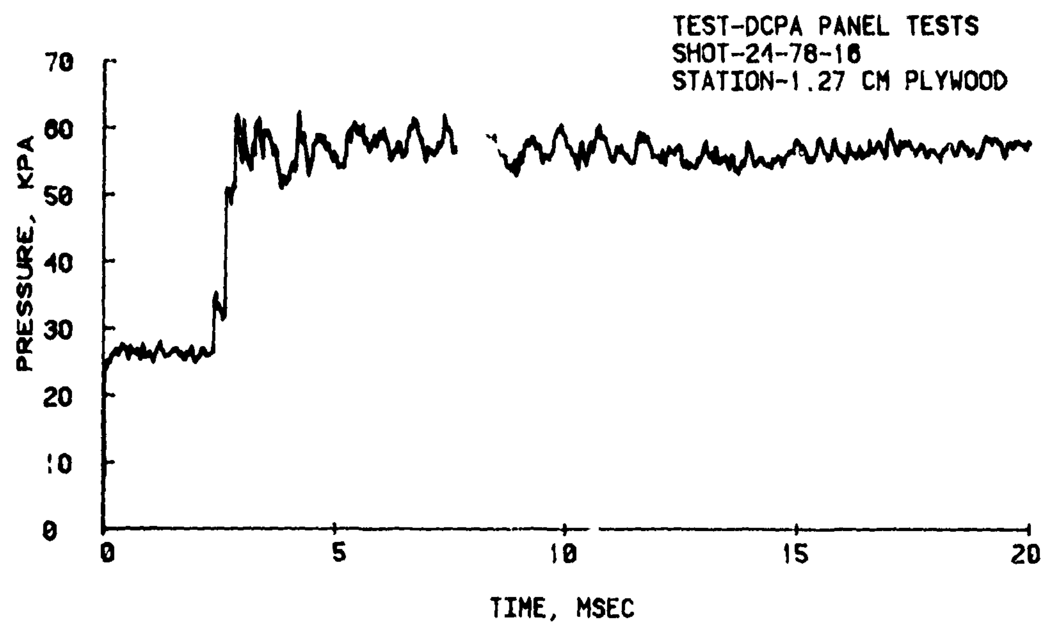

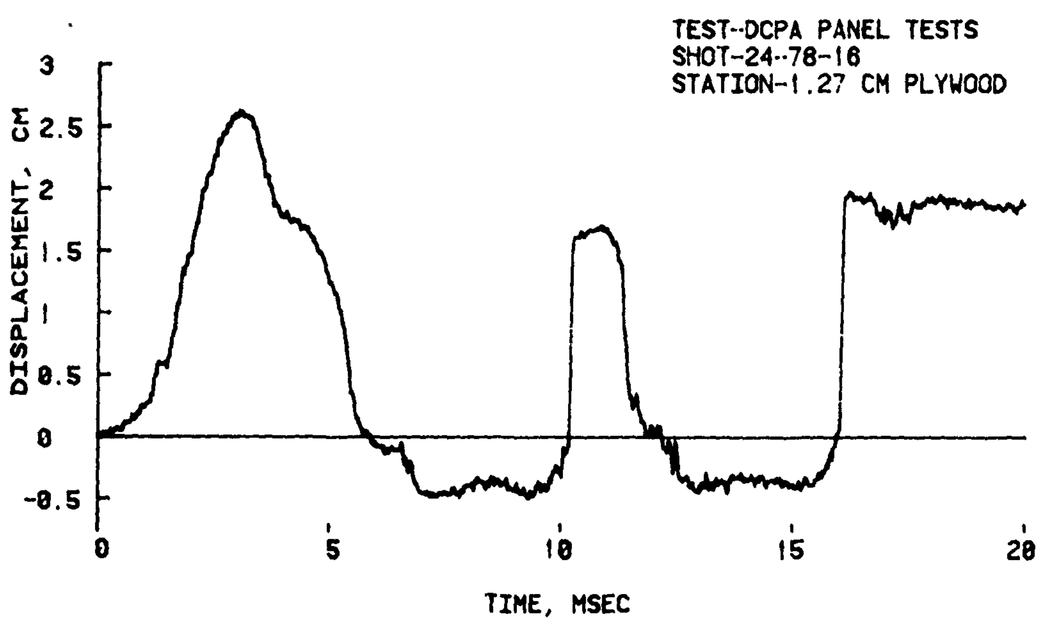

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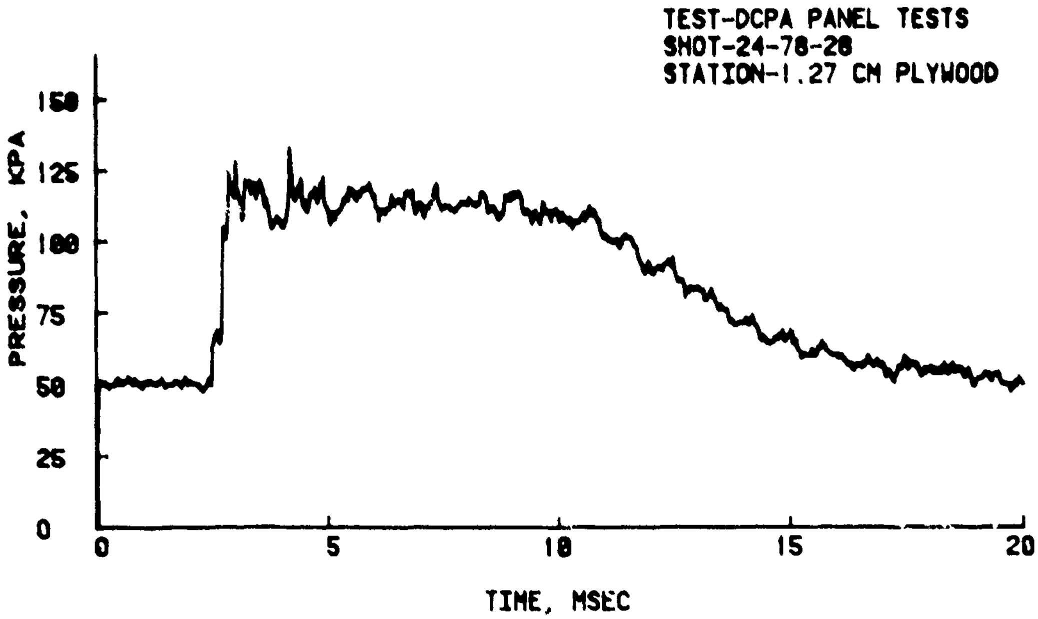

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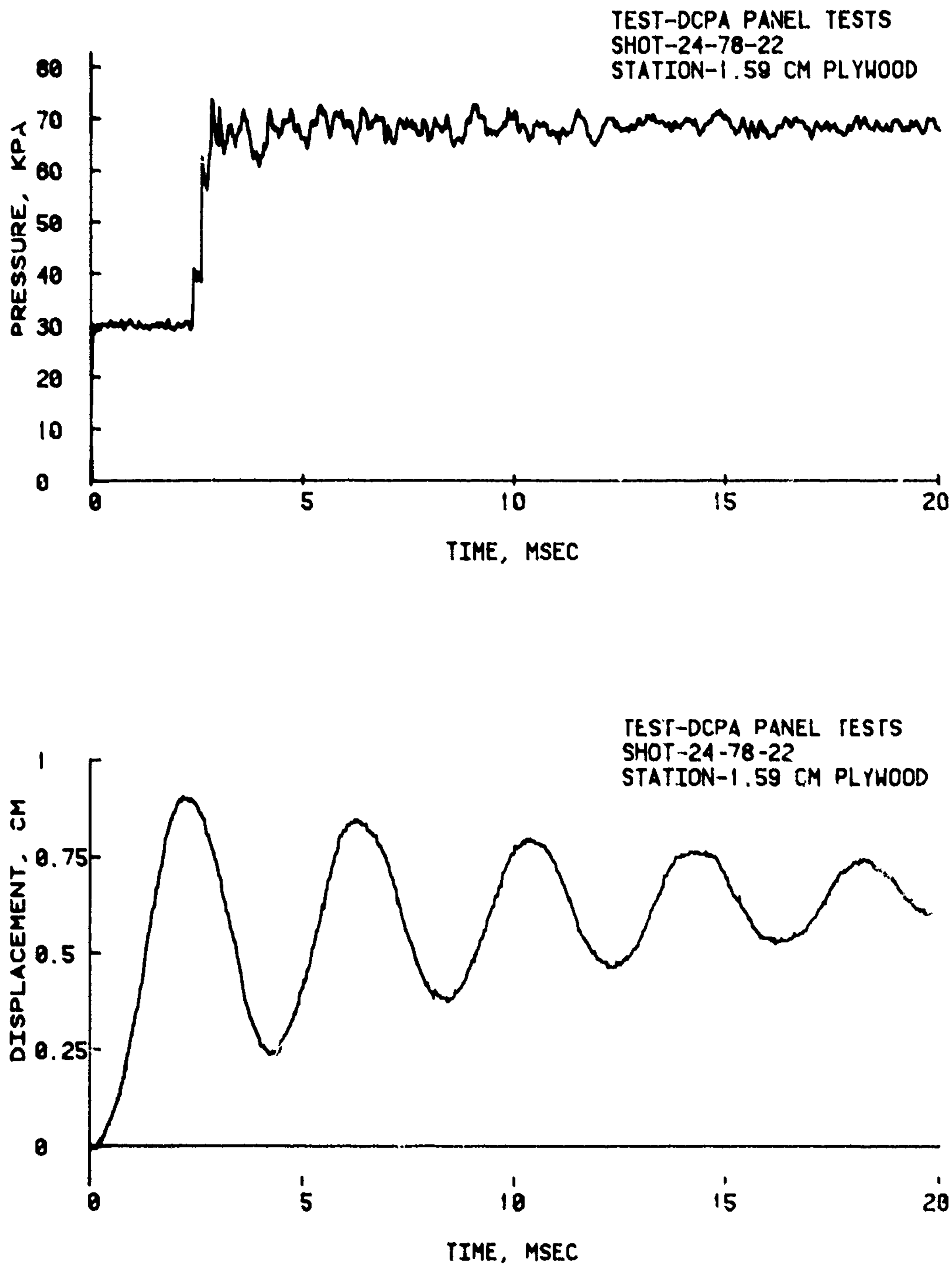
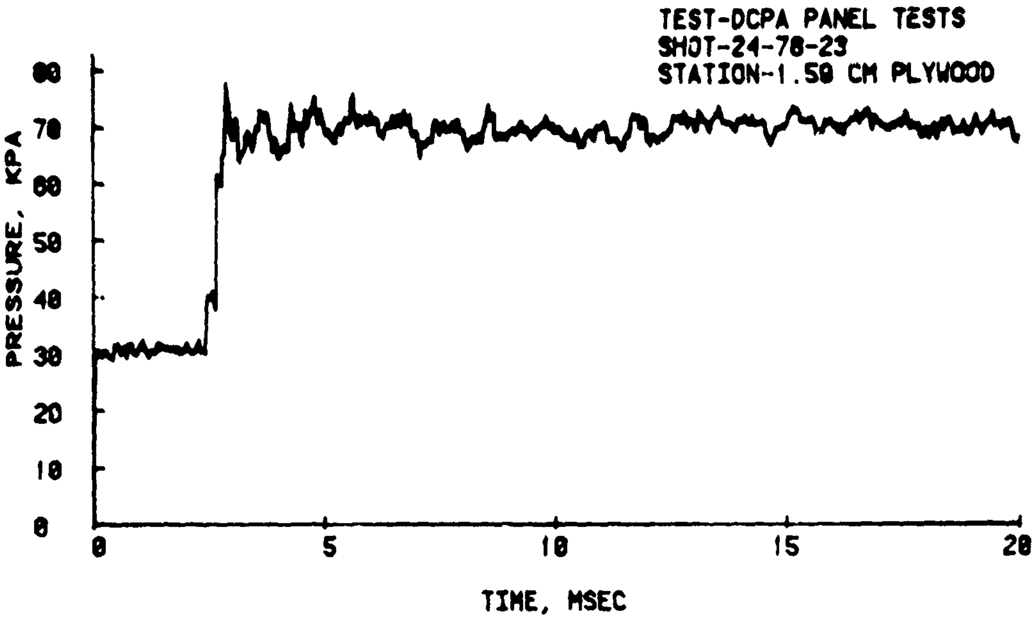
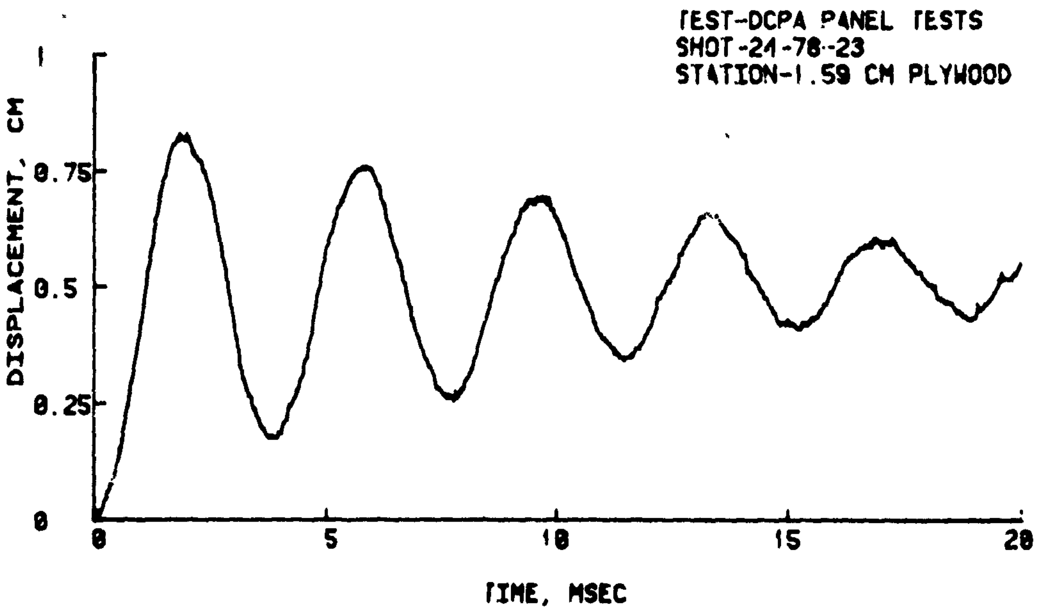


Figure A-2. Records for 1.59 cm Panels





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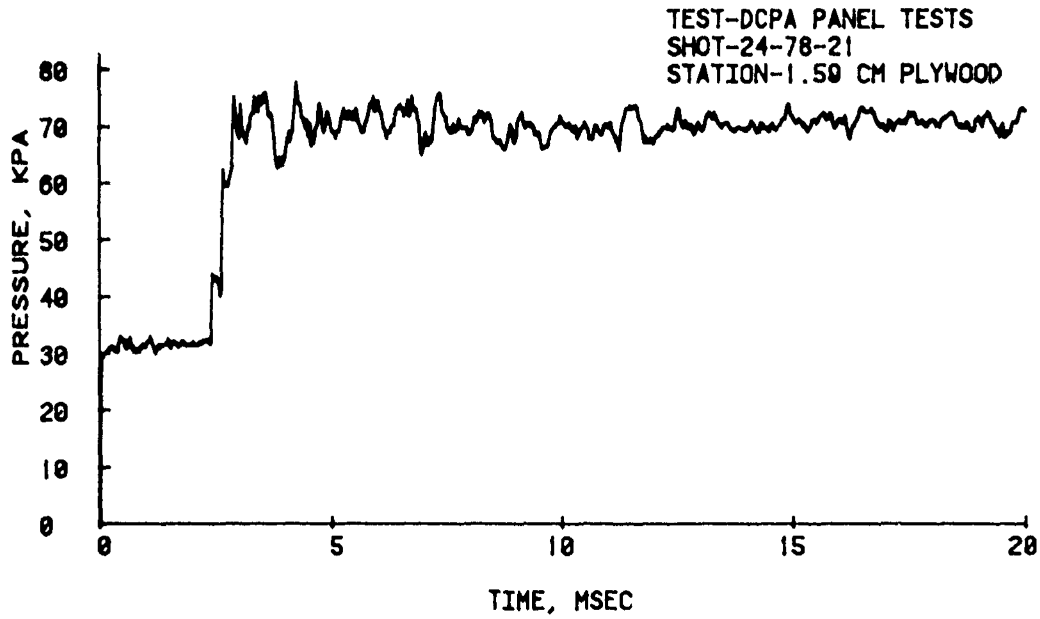

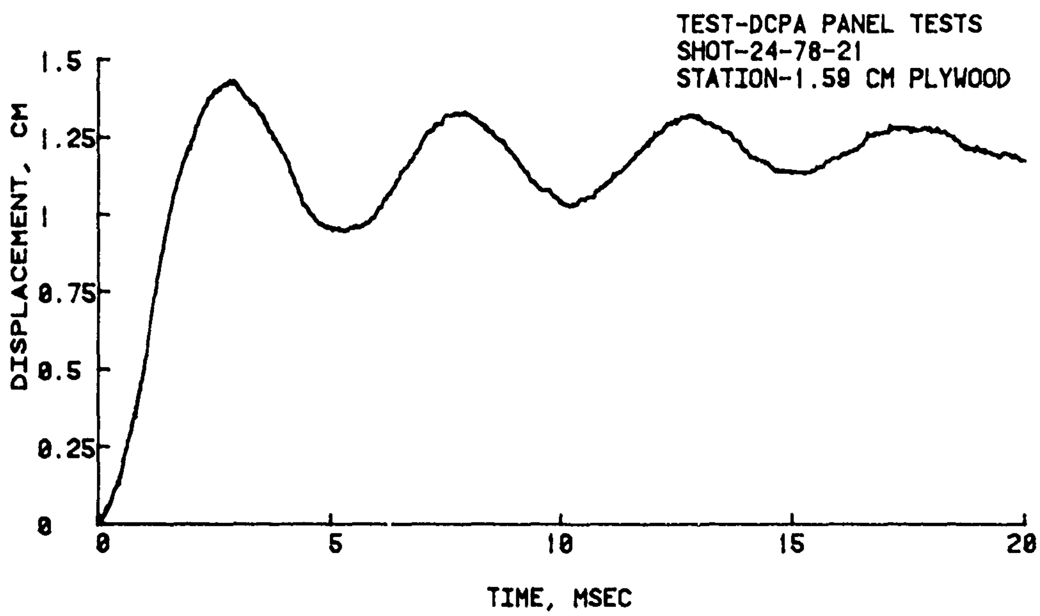

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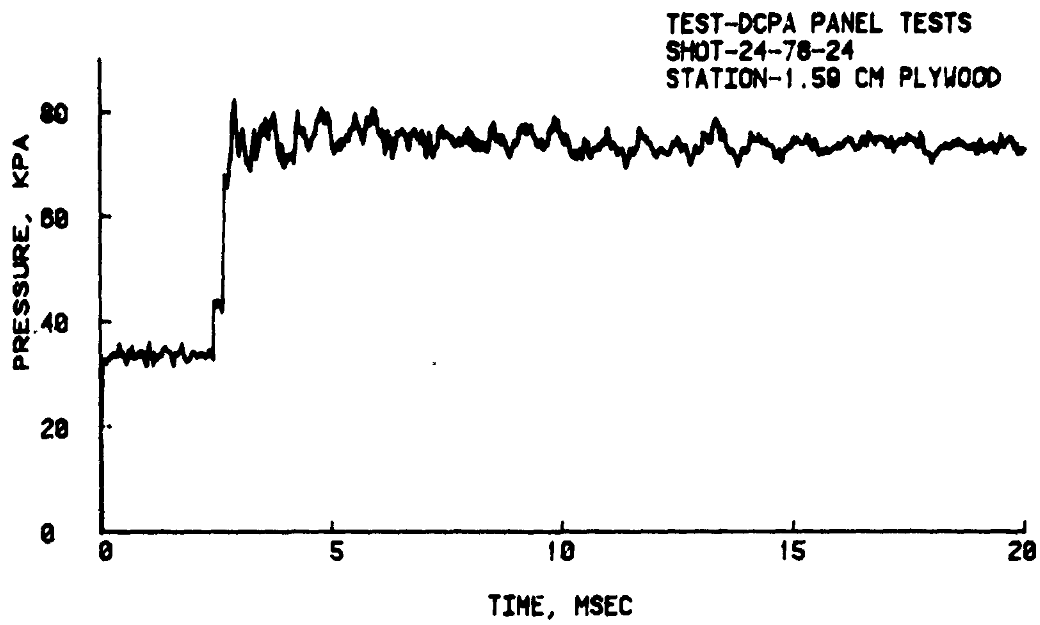

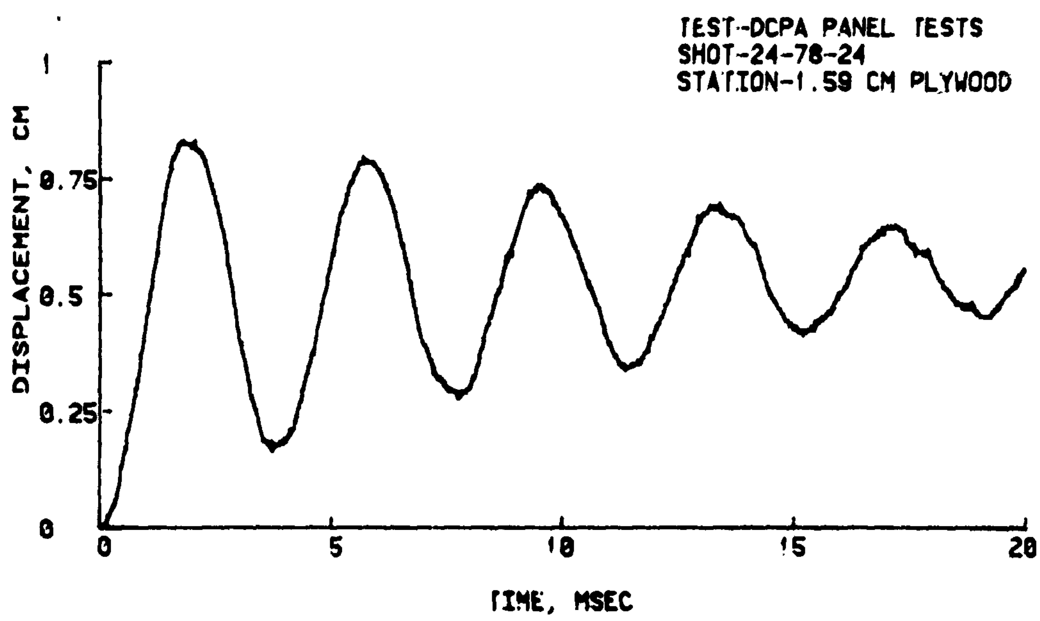

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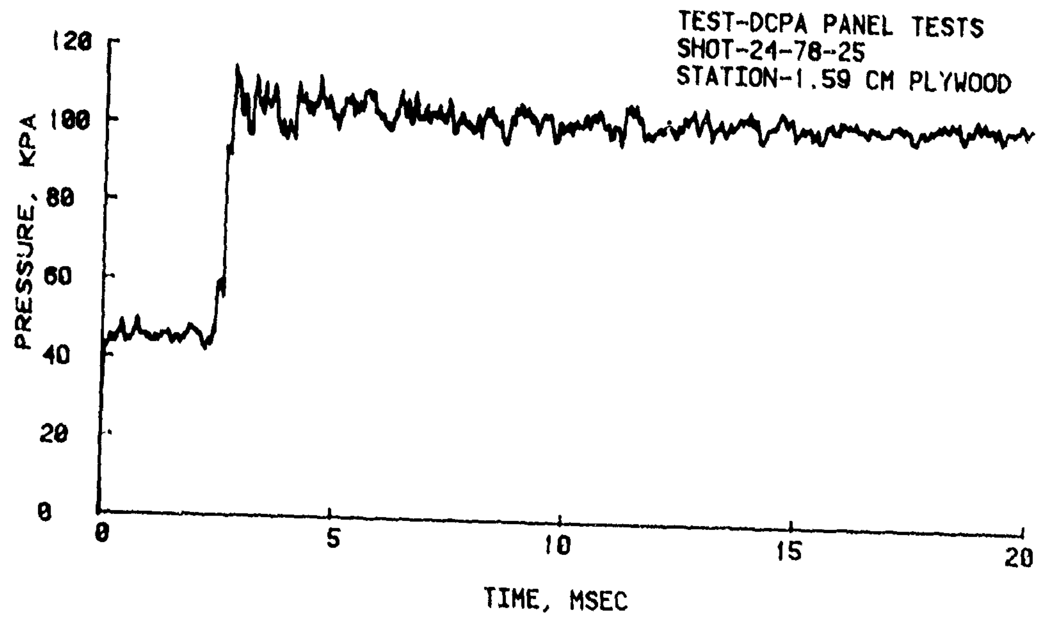

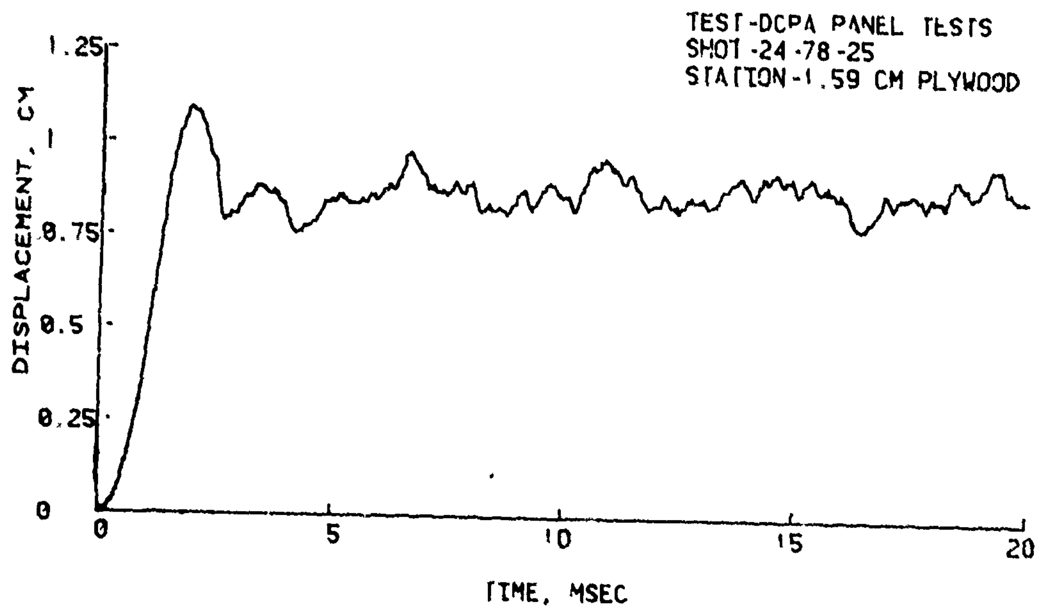

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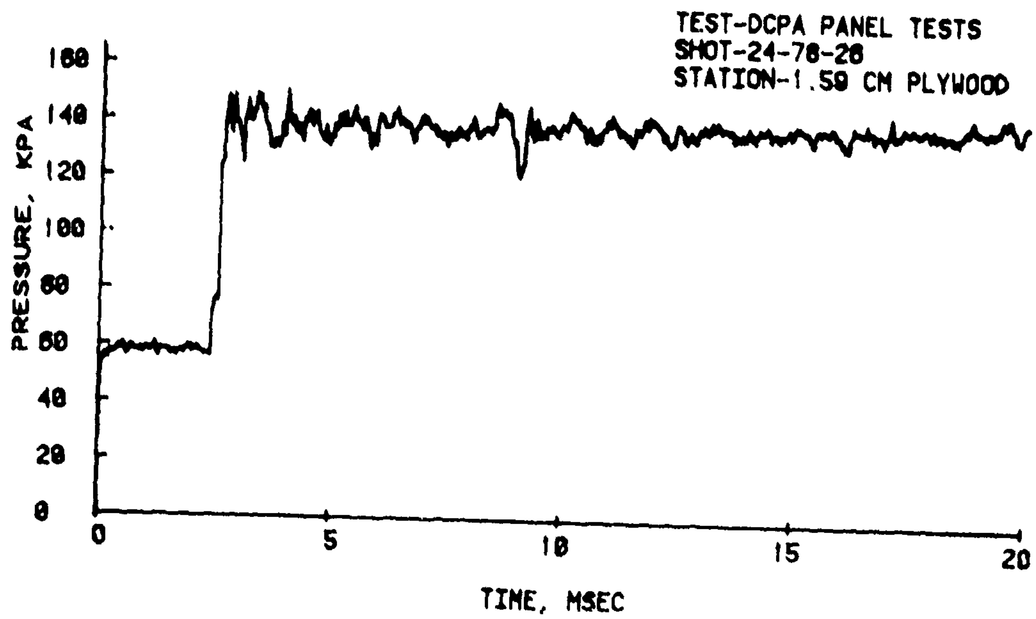

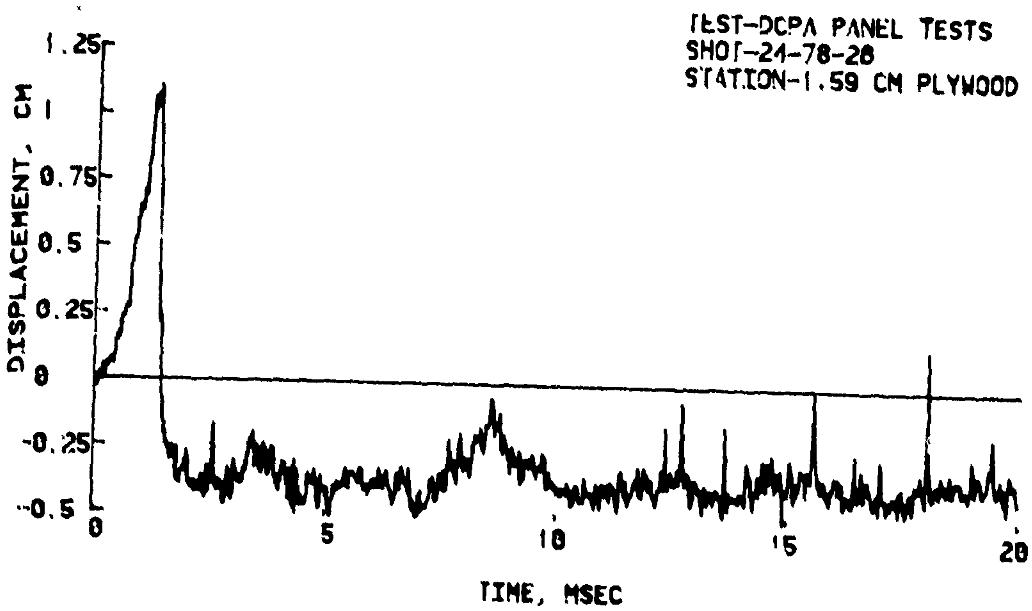

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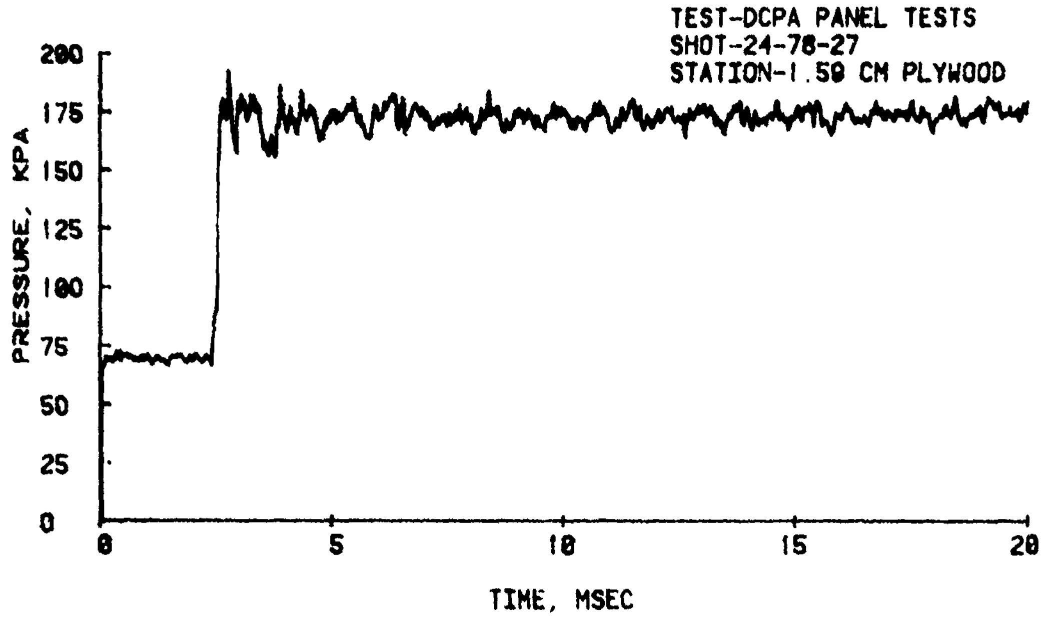

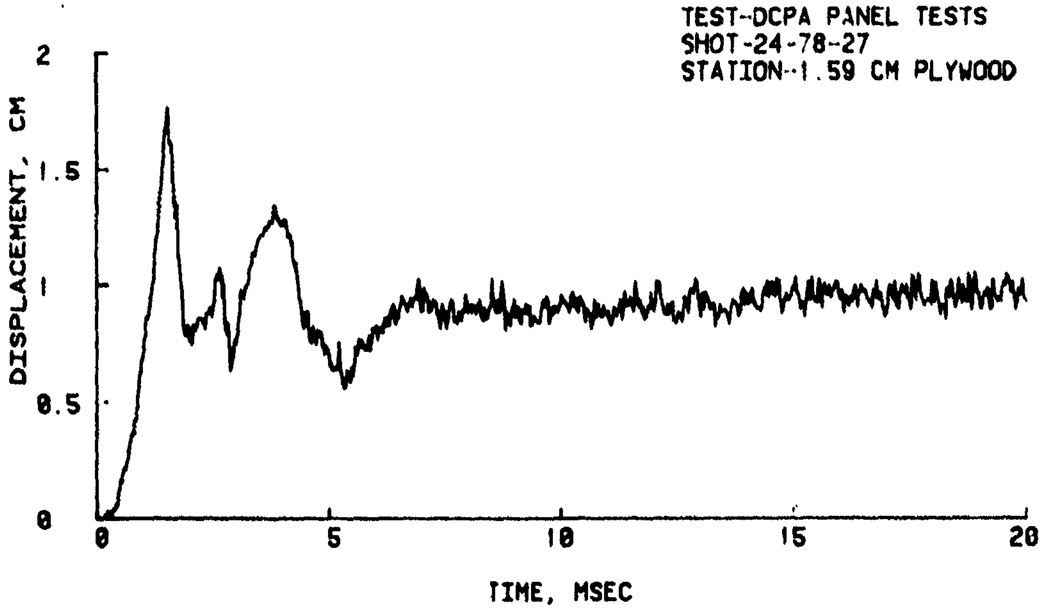

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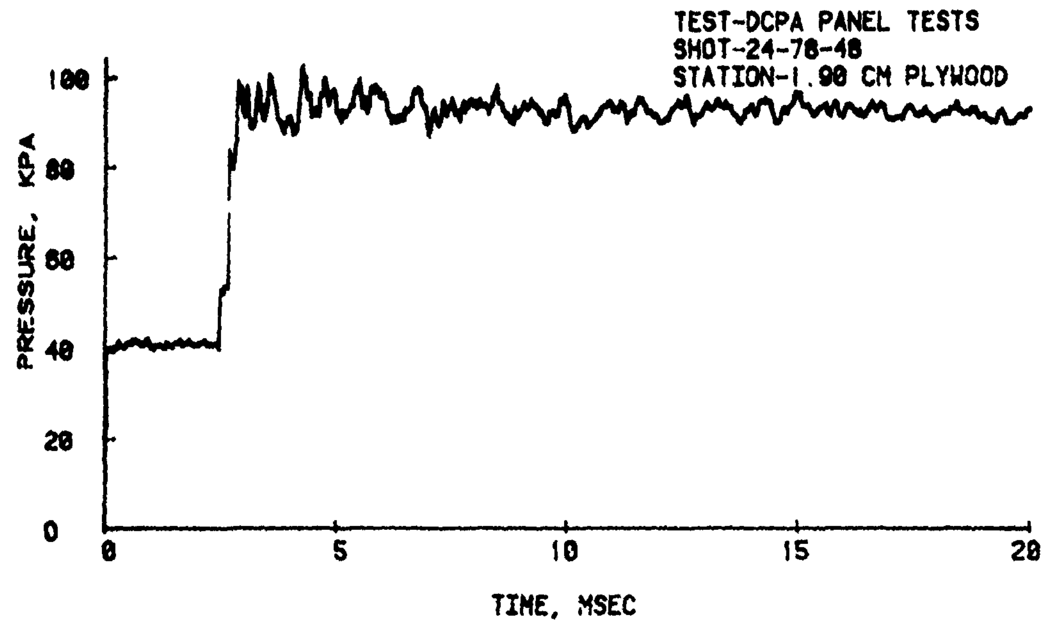

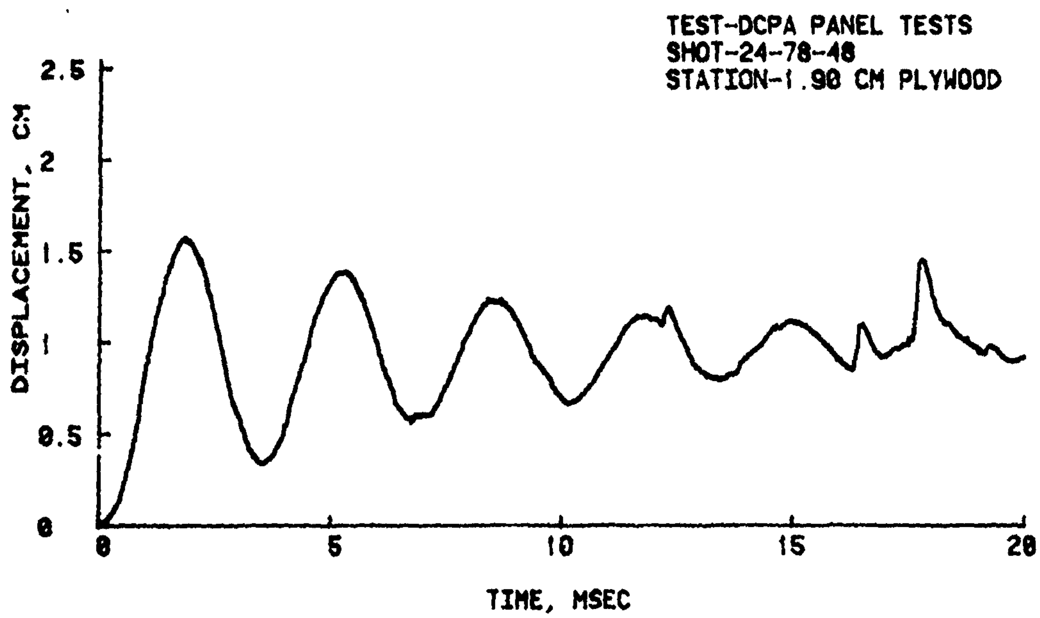

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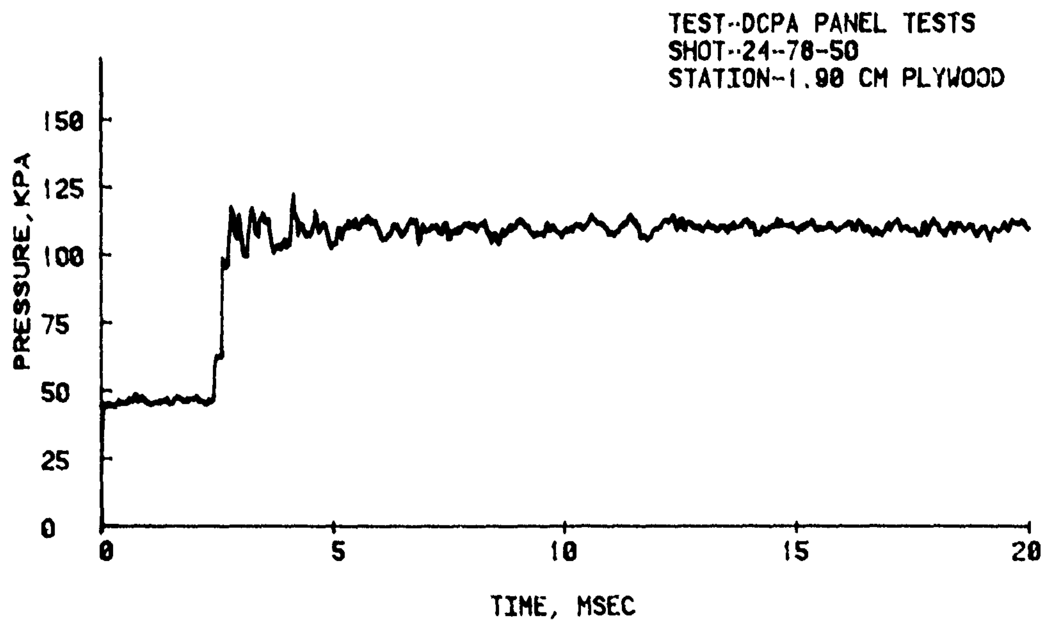

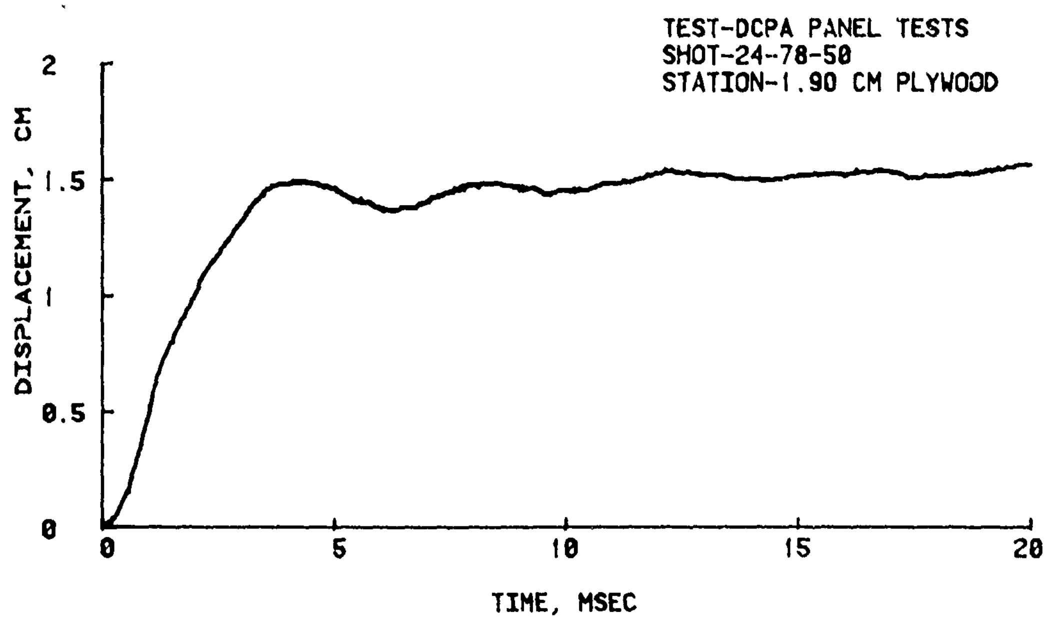

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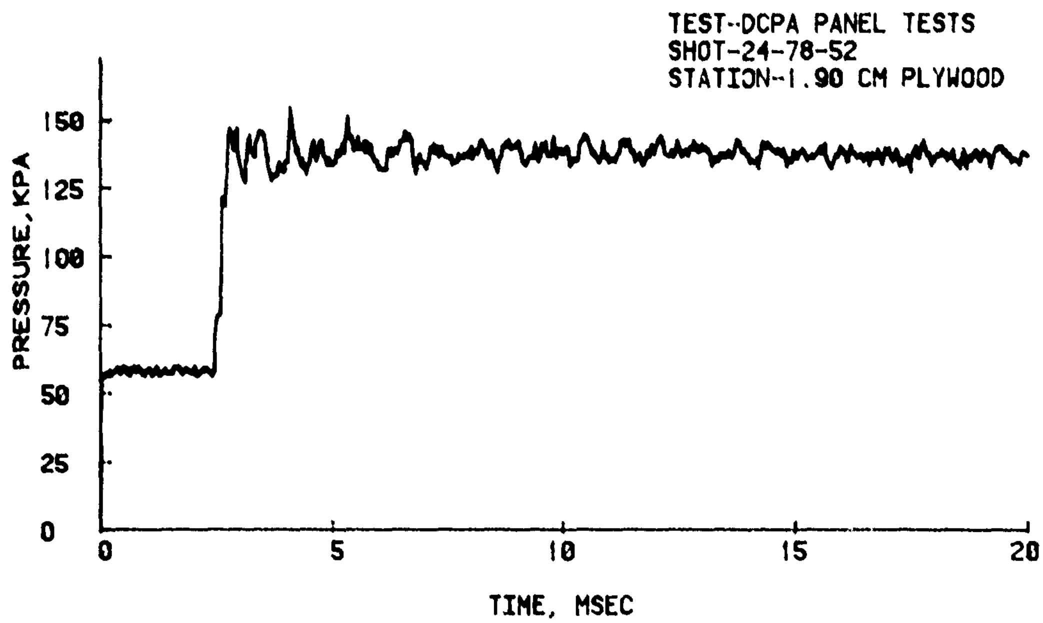

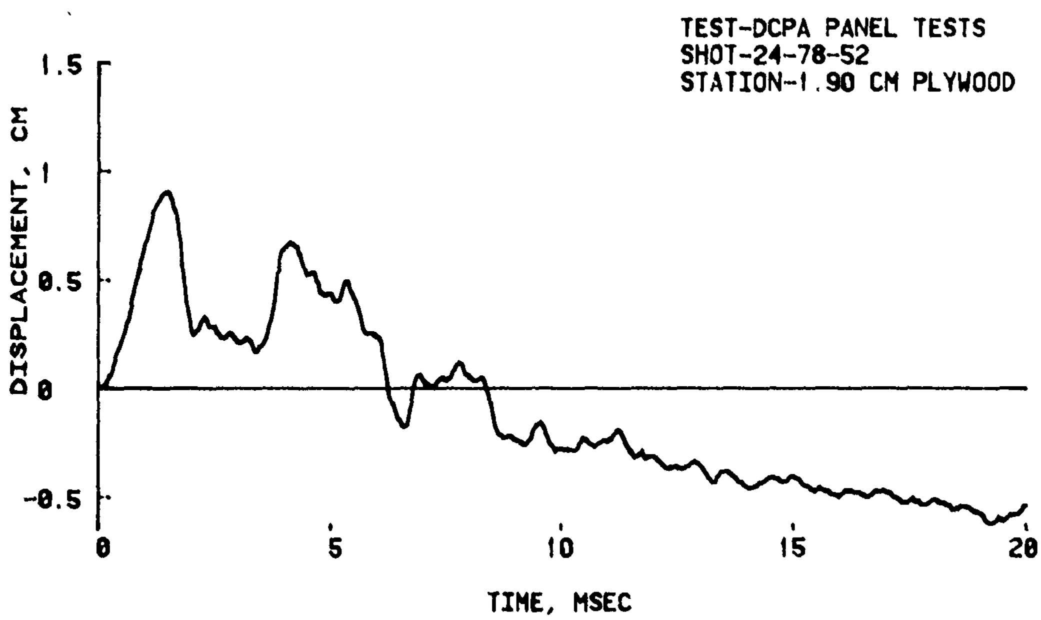

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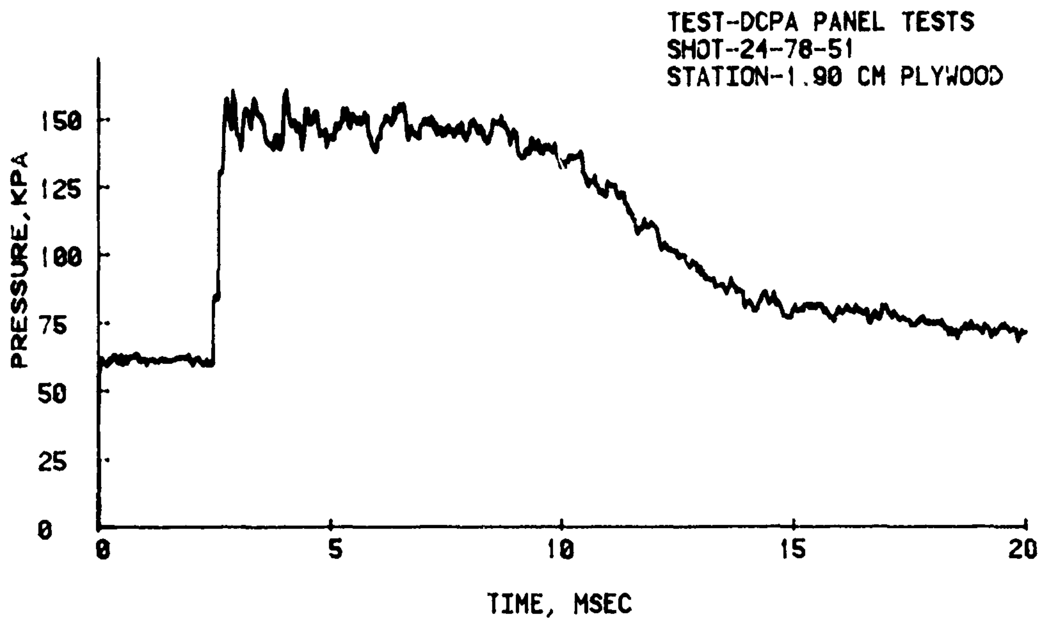

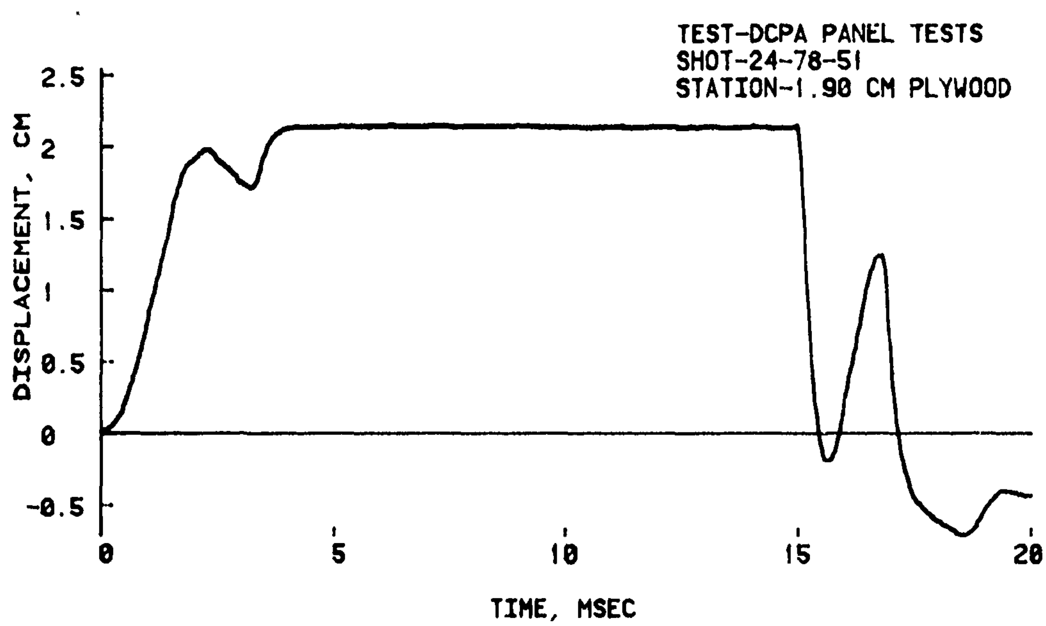

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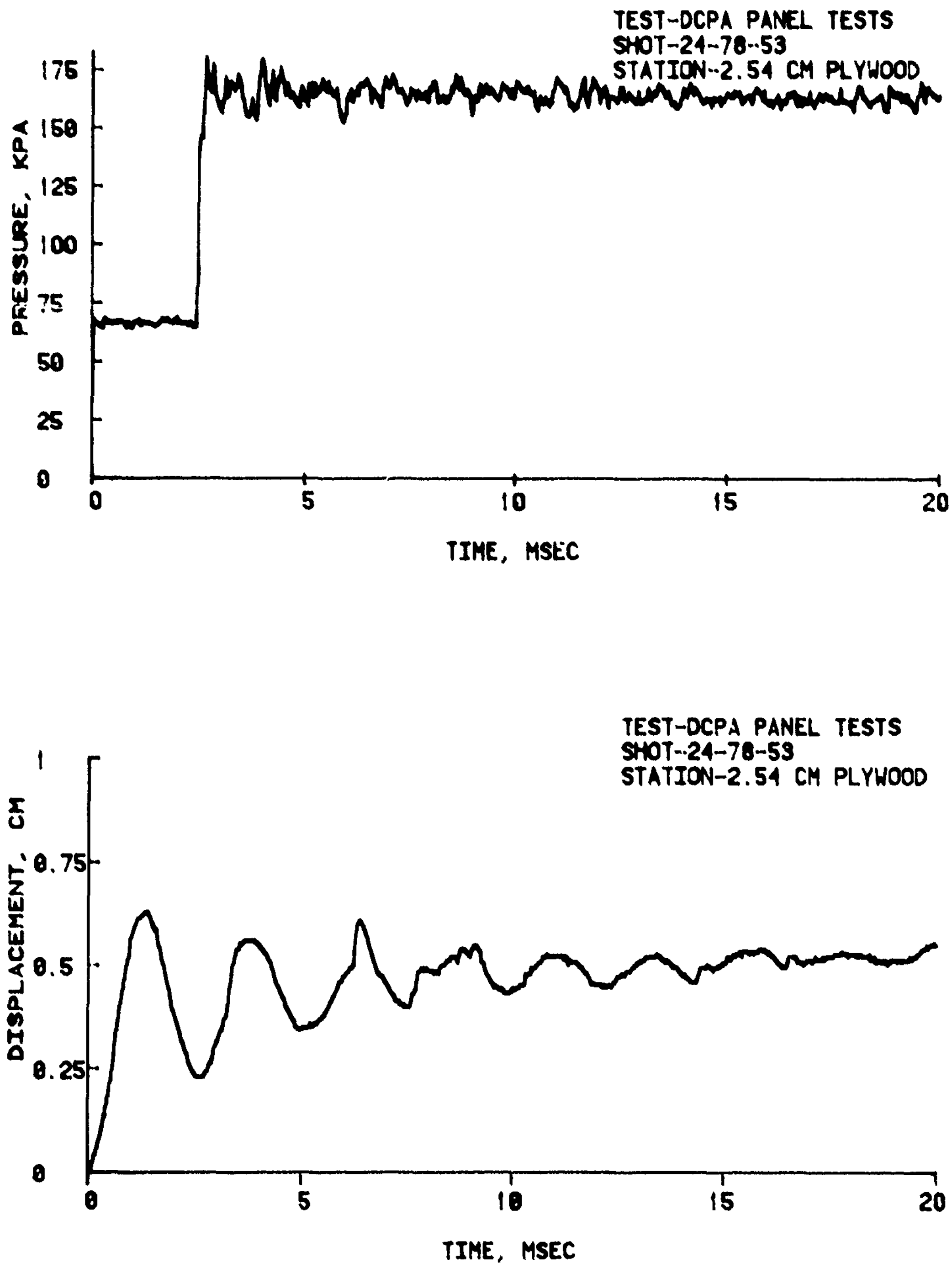
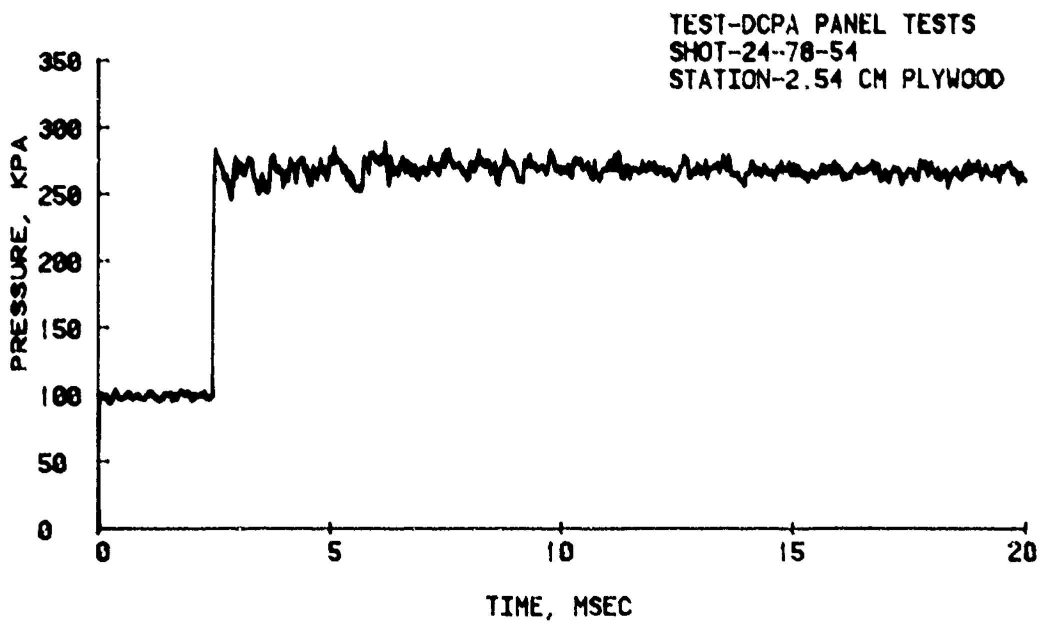
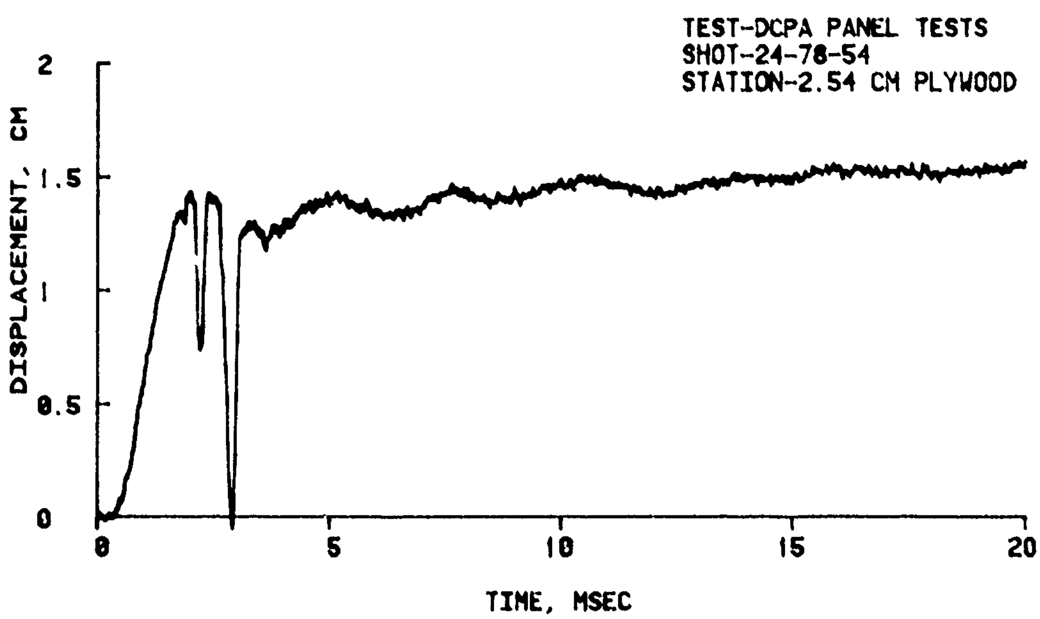


Figure A-4. Records for 2.54 cm Panels





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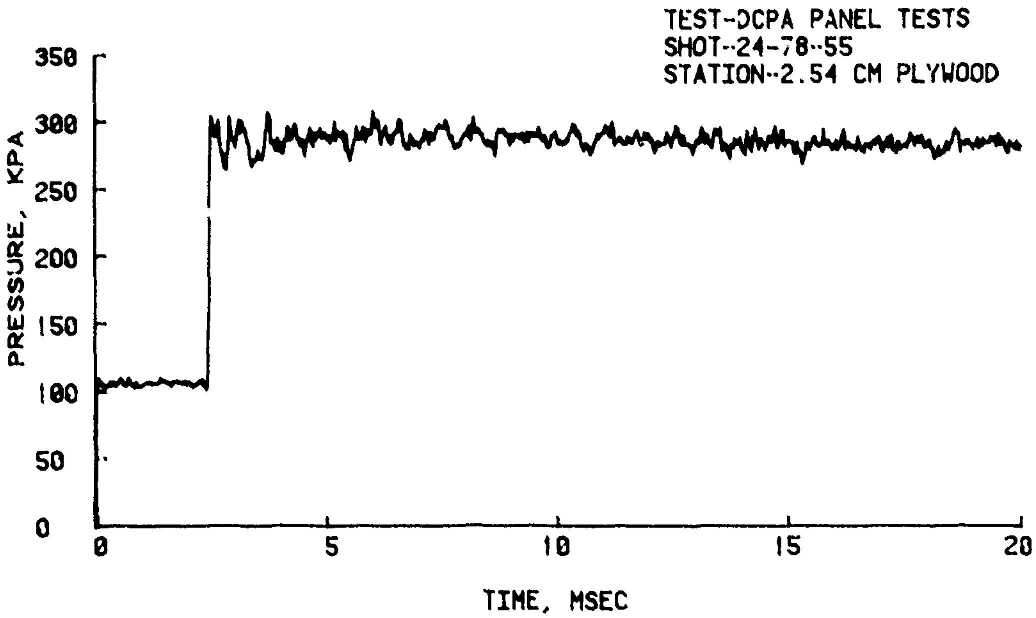

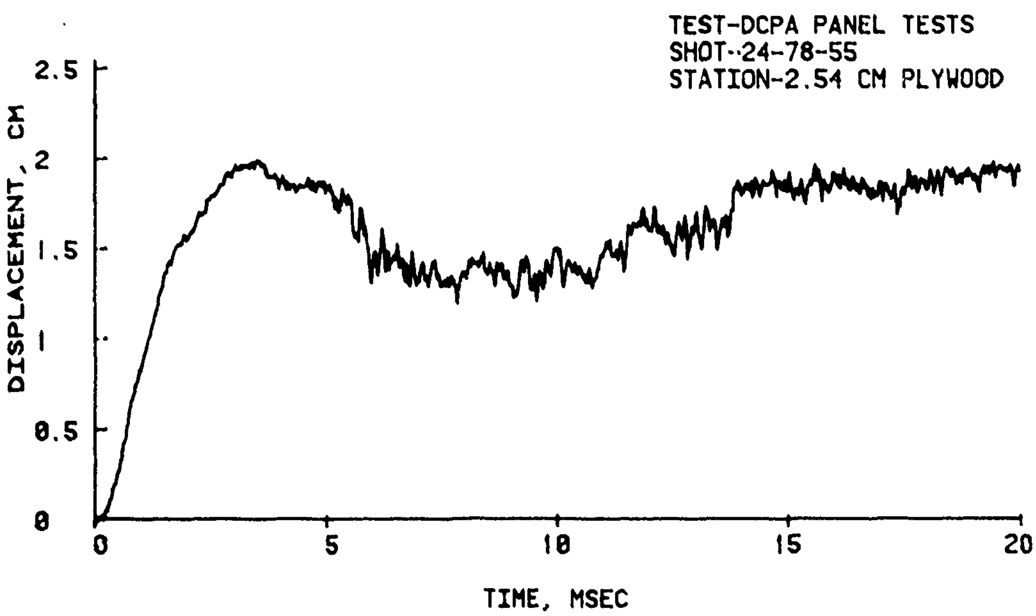

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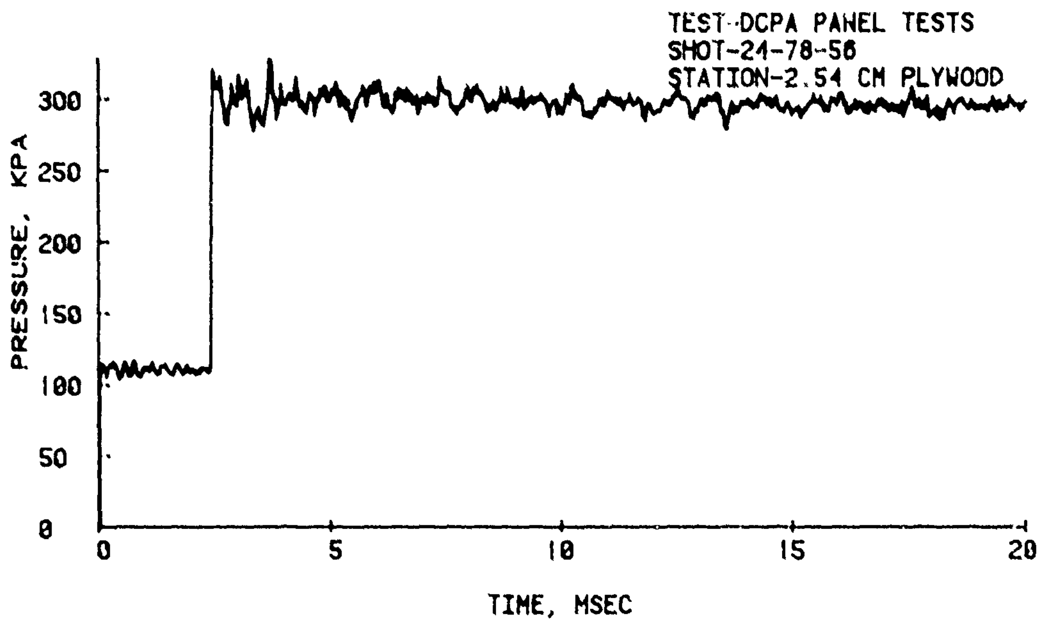

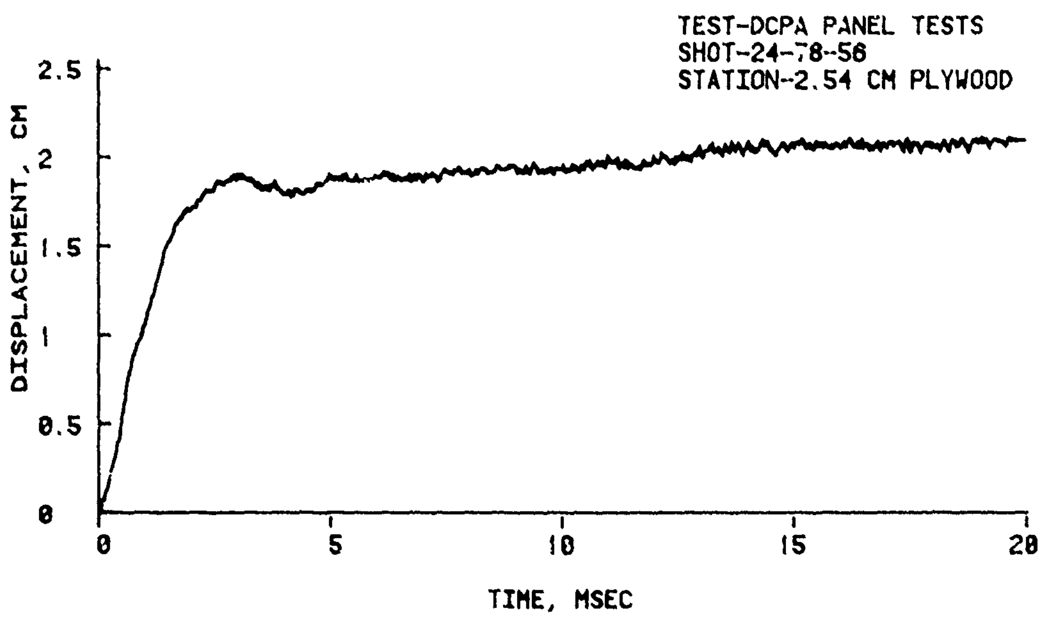

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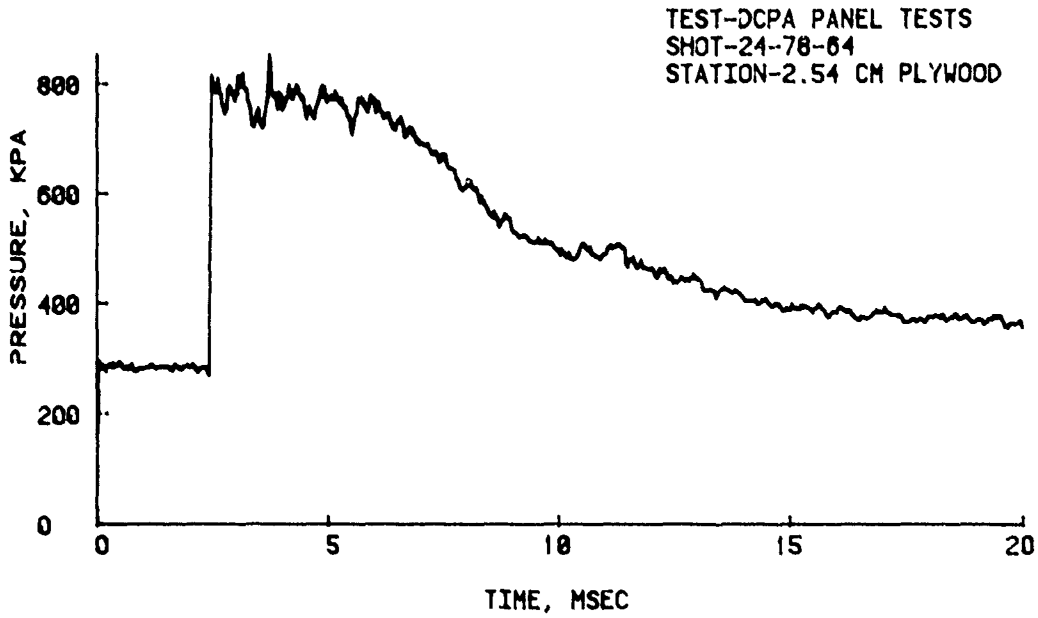

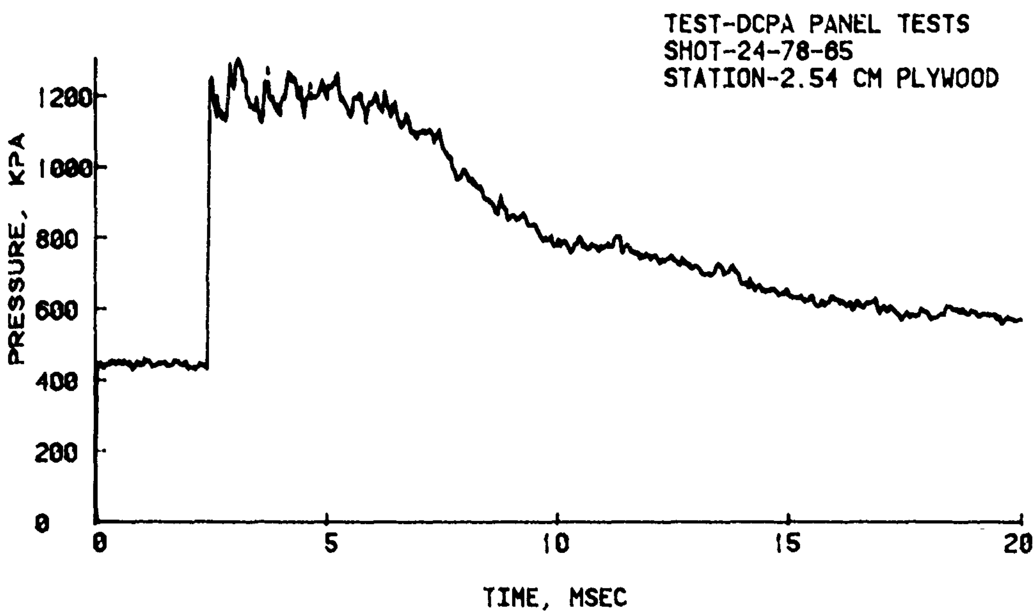

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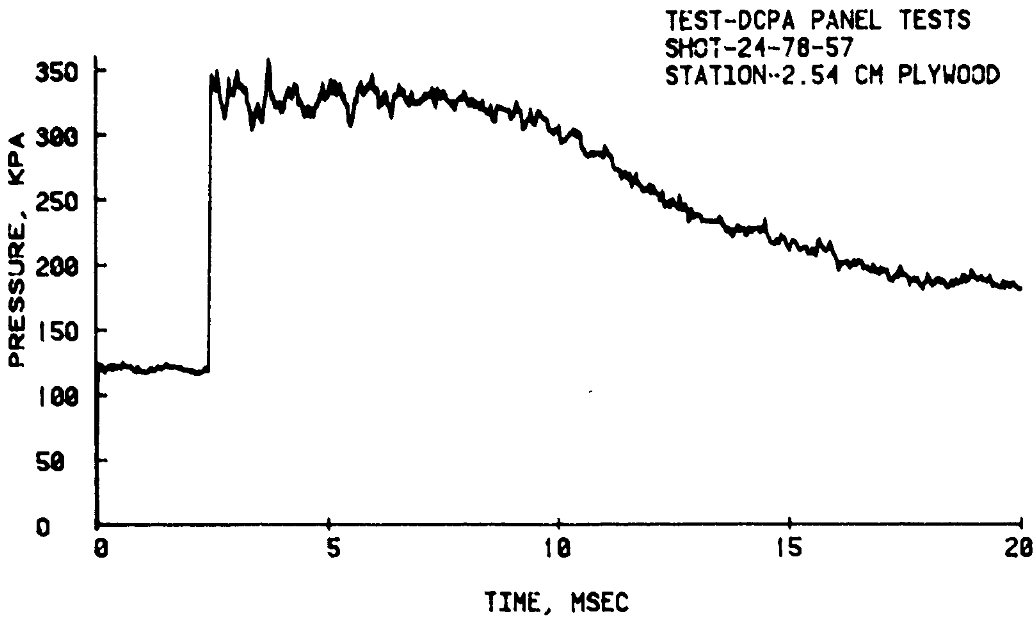

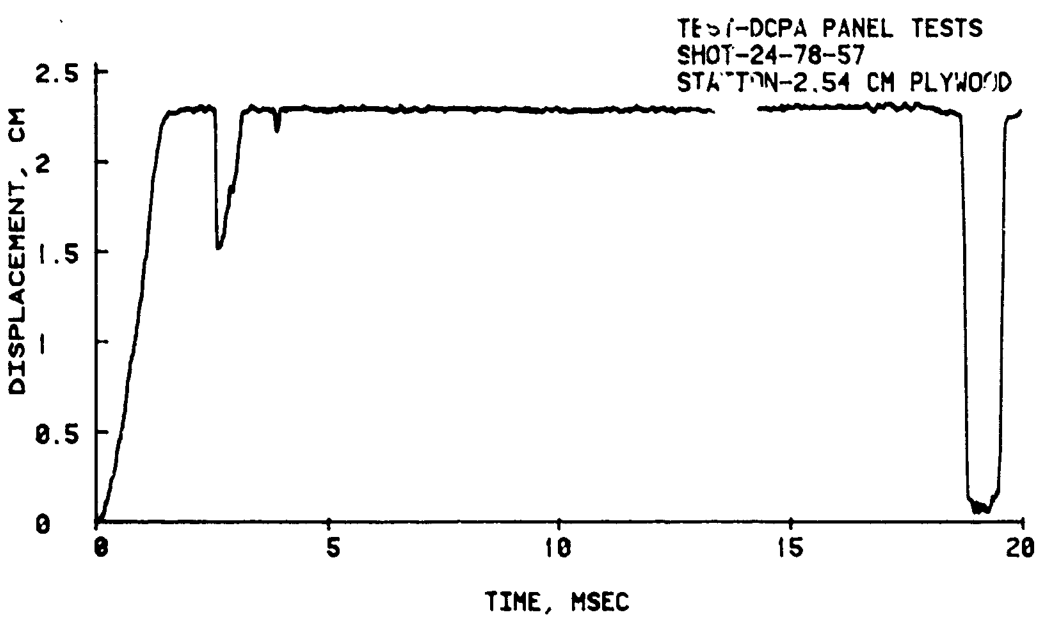

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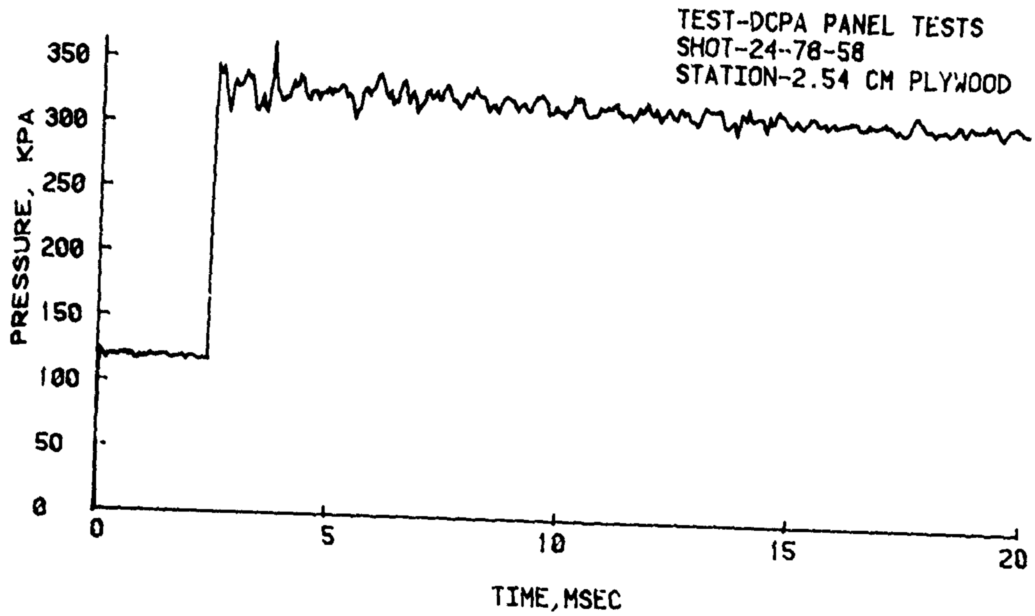

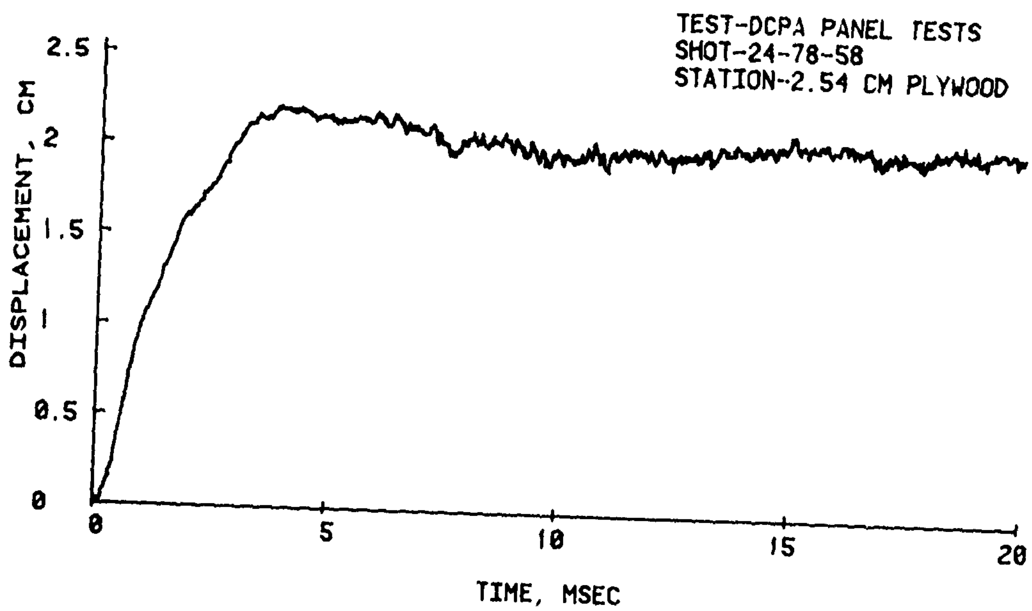

Figure A-4 (Cont). Records for 2.54 cm Panels

LIST OF SYMBOLS

C	constant, no units
E	Modulus of elasticity, kPa
F_b	Allowable bending stress, kPa
$F_{c\perp}$	Allowable bearing stress-load perpendicular to plane of outer ply actually in bearing, kPa
F_s	Allowable rolling shear stress, kPa
I	Effective moment of inertia, cm^4/cm width
(Ib/Q)	Rolling shear constant, cm^2/cm width
ℓ	Clear span, cm
ℓ_e	Required end bearing length, cm
P_b	Allowable load-bending moment, kPa
P_m	Useful allowable load, kPa
P_m total	Total allowable load-supported four sides, kPa
pps	Pictures per record
P_{st}	Allowable load-rolling shear stress, kPa
S or KS	Effective section modulus, cm^3/cm width
t	Nominal panel thickness, cm
Y_b	Bending deflection (elastic) under uniform load, cm
Y_s	Shear deflection (elastic) under uniform load, cm

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